

Western Energy Resource Development
A Network for Monitoring the Impact on
Surface Water Quality

(U.S.) Environmental Monitoring Systems Lab.
Las Vegas, NV

Jul 80



U.S. Department of Commerce
National Technical Information Service

NTIS

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA-600/4-80-036	2.	3. RECIPIENT'S ACCESSION NO. 7/2/80 - AEA PB 80 199839
4. TITLE AND SUBTITLE WESTERN ENERGY RESOURCE DEVELOPMENT A Network for Monitoring the Impact on Surface Water Quality	5. REPORT DATE JULY 1980 ISSUING DATE.	
7. AUTHOR(S) Robert W. Thomas	6. PERFORMING ORGANIZATION CODE	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Monitoring Systems Laboratory Office of Research and Development U.S. Environmental Protection Agency Las Vegas, Nevada 89114	8. PERFORMING ORGANIZATION REPORT NO.	
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency--Las Vegas, NV Office of Research and Development Environmental Monitoring Systems Laboratory Las Vegas, Nevada 89114	10. PROGRAM ELEMENT NO. TBD625	
	11. CONTRACT/GRANT NO.	
	13. TYPE OF REPORT AND PERIOD COVERED Final	
	14. SPONSORING AGENCY CODE EPA/600/07	
15. SUPPLEMENTARY NOTES NTIS-Only distribution		
16. ABSTRACT A monitoring network to assess the impact of energy resource development on surface water quality in Western Mountain States is developed. A literature review of energy resource development activities, known and potential pollutants, monitoring strategies, and data requirements for statistical analyses located the river systems most likely to be affected, determined parameters of interest, and identified deficiencies in existing monitoring operations. The most cost-effective monitoring strategy was determined to be a system designed to detect surface water quality trends over a 2- to 4-year period. Twenty-five existing U.S. Geological Survey stations located near the mouths of rivers where energy resource development is occurring, were selected for inclusion in a monitoring network. For most water quality parameters it will be necessary to sample approximately every ten days in order to obtain enough data to permit meaningful trend analyses. Forty-two water quality parameters were identified. In addition, monthly sediment, seasonal biological, and semiannual organic chemical sampling and analyses are recommended. The described system would identify trends in surface water quality but would require additional efforts to determine the causes of those trends. It would provide an early warning for regional problems and permit the timely execution of any necessary mitigation or corrective measures.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
5 water quality 4 water pollution and control 2 coal mining 3 oil shale 1 coal gasification	Western Energy Resource Development Area	08I 13B,H 68D
18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

DISCLAIMER

This report has been reviewed by the Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

6-1/2"

9-1/8"

BEGIN
LAST LINE
OF TEXT

3/8"

ii

PAGE NUMBER

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

FOREWORD

Protection of the environment requires effective regulatory actions based on sound technical and scientific data. The data must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of exposure to specific pollutants in the environment requires a total systems approach that transcends the media of air, water, and land. The Environmental Monitoring Systems Laboratory at Las Vegas contributes to the formation and enhancement of a sound monitoring-data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report presents the design and rationale for a network for monitoring the impact on surface-water quality of western energy resource development. It proposes trend-monitoring strategy that will permit monitoring agencies to detect water quality trends in energy resource development areas. Intense surveys or other studies will be necessary to determine the causative factors for observed trends.

The recommendations may affect Federal, State and local water-quality monitoring agencies, particularly those concerned with the impact of western energy resource developments. Further information on this report and the network it describes may be obtained from the Environmental Monitoring Systems Laboratory in Las Vegas, Nevada.

Glenn E. Schweitzer
Director
Environmental Monitoring Systems Laboratory
Las Vegas, Nevada

BEGIN
LAST LINE
OF TEXT

3/8"

iii

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD.
BEGIN
SECTIONS
HERE

SUMMARY

Development of fossil fuel, uranium, and other energy reserves located in the Western United States is essential. These resources, located primarily in the Northern Great Plains and the Colorado Plateau, consist of extensive gas and oil fields and coal, oil shale, and uranium deposits. Because of our national dependence on oil and gas, conversion of coal to liquid and gaseous forms is anticipated.

Resource development cannot be accomplished without some adverse environmental impact. The potential for significant degradation of air, land, or water quality exists. Pollution may occur during any or all stages of the extraction, refining, transportation, conversion, or utilization process. Secondary impacts resulting from increased population pressures, water management, and development of supportive industries are expected. The proximity of energy resources to recreational areas (frontispiece) will result in some impact, even if only to visual aesthetics. With careful planning, management, and regulation, these impacts can be minimized and held to tolerable levels.

The objective of this report is to develop a monitoring network to assess the impact of energy resource development on water quality in the Western Mountain States (Montana, Wyoming, Colorado, Utah, New Mexico, and Arizona). Such a network is required to determine the impact of cumulative effects from many simultaneous resource development efforts and to detect changes brought about by pollution from unregulated or unconsidered parameters in time to impose any necessary mitigation measures. Present monitoring activities are inadequate to detect subtle changes in most parameters over a 2-to 4-year period in western rivers and streams.

A monitoring network designed to detect trends in surface-water quality is proposed on the basis of our present knowledge. In such a network, the total number of observations from the network is minimized at the expense of the number of stations in order to provide statistically valid data. This network consists of 25 stations:

USGS Station Number

Description

09380000	Colorado River at Lees Ferry, Ariz.
09368000	San Juan River at Shiprock, N. Mex.
09379500	San Juan River near Bluff, Utah
09180500	Colorado River near Cisco, Utah
09152500	Gunnison River near Grand Junction, Colo.
09132500	North Fork Gunnison River near Somerset, Colo.
09217000	Green River near Green River, Wyo.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

09224700	Blacks Fork near Little America, Wyo.
09251000	Yampa River near Maybell, Colo.
09260000	Little Snake River near Lily, Colo.
09306500	White River near Watson, Utah
09306222	Piceance Creek at White River, Colo.
09314500	Price River at Woodside, Utah
09328500	San Rafael River near Green River, Utah
09315000	Green River at Green River, Utah
06635000	Medicine Bow River above Seminoe Res., Wyo.
06438000	Belle Fourche River near Elm Springs, S. Dak.
06337000	Little Missouri River near Watford City, N. Dak.
06130500	Musselshell River at Mosby, Mont.
06214500	Yellowstone River at Billings, Mont.
06294700	Bighorn River at Bighorn, Mont.
06308500	Tongue River at Miles City, Mont.
06326500	Powder River near Locate, Mont.
06329500	Yellowstone River near Sidney, Mont.
08251500	Rio Grande River near Lobatos, Colo.

These include 17 National Stream Quality Accounting Network (NASQAN) stations and 8 other U.S. Geological Survey (USGS) stations. Stations are located near the mouths of rivers that drain areas where energy resource development is presently occurring. A similar network for ground-water monitoring needs to be implemented, but available data are insufficient to adequately determine station locations.

Biological, physical, and chemical parameters likely to be affected by energy resource development activities were determined. Physical and chemical water quality parameters recommended for monitoring are listed below. Parameters marked with * should be measured in sediment samples as well as in water.

Alkalinity, total	Flow
Aluminum, dissolved	Fluoride, dissolved
Ammonia - nitrogen	Iron, total*
Arsenic, total*	Kjeldahl nitrogen
Barium, total*	Lead, total*
Biochemical oxygen demand, 5-day*	Magnesium, dissolved
Bicarbonate, dissolved	Molybdenum, total*
Boron, total	Nickel, total*
Carbon, dissolved organic	Nitrate nitrogen
Carbon, total organic*	Nitrite nitrogen
Cadmium, total	Oxygen, dissolved
Calcium, dissolved	Oil*
Carbonate, dissolved	pH
Chloride, dissolved or ionic	Phenols*
Chromium, total*	Sediment grain size
Coal content	(sediment samples only)
(sediment samples only)	Selenium, total*
Conductance, specific @25°C	Sodium, dissolved
Copper, total*	Solids, total suspended
Cyanide, total*	Solids, total dissolved

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

Sulfate, dissolved
Temperature
Turbidity

Uranium, total*
Vanadium, total*
Zinc, total*

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

Biological monitoring is presently considered the most feasible method of assessing the impact of introducing numerous organic chemicals into the environment. Unfortunately, biological monitoring techniques are not well developed at present; nevertheless samples should be collected and preserved for future analyses. Sampling and analysis of carp and catfish (or similar species) for bioaccumulation of toxic elements and compounds, fecal coliform and fecal streptococci analyses, and collection and analyses of periphyton and macrobenthos should be conducted. Portions of the fish samples, macrobenthos, and a special small-fish collection (dace or gambusia) should be preserved for future analysis.

In order to obtain sufficient data for trend analysis, water samples should be collected about every 10 days (between 7 and 14 days). Temperature, flow, pH, and specific conductance data should be collected continuously. Sediment should be sampled monthly; biological samples seasonally or semiannually (except for monthly bacteriological analyses). Collection of semiannual water samples for organic analyses is recommended.

The network described will detect trends in monitored parameters, but it will not provide adequate data to determine the causes of these trends. Network data will need to be augmented by data from other stations or from intense surveys to define the source of degradation. In addition, research on biological monitoring techniques, organic chemical analyses, data interpretation techniques, and development of monitoring instrumentation are necessary. Further definition of a trend-monitoring network for ground water is required.

Data collected should be stored in a computerized data base. All data should be stored either within the same data base or within the same computer system to facilitate merging physical, chemical, and biological data. EPA's STORET data base and computer system are recommended for this purpose. Because of the large volume of data collected by the USGS, software and other procedures should be developed to facilitate data accessibility and transfer between EPA's STORET system and USGS's WATSTORE data base. Close attention to quality assurance should be paid at all stages of collection, analysis, data reduction, and data entry into computer data bases.

The network described is of value only if it is implemented. Present data and monitoring activities are not adequate to permit detection of subtle trends in most parameters over a 2-to 4-year period in western waters. The network described could be implemented by eliminating other stations or reducing the number of parameters or sampling frequency at other stations, especially those near the energy resource monitoring network stations. The early implementation of such a network is strongly recommended.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

CONTENTS

	Page
Foreword.	iii
Summary	iv
Figures	viii
Tables	ix
Introduction.	1
Conclusions	3
Recommendations	5
Background.	7
Energy Resource Development	10
Coal.	10
Oil shale	20
Gas and oil	22
Other energy resources.	24
Transportation.	26
Conversion and refining	28
Power generation.	28
Waste disposal.	28
Other	29
Water availability.	32
Elemental pollutants.	32
Possible organic pollutants	41
Present Water Monitoring System	55
Network Design for Monitoring Energy Development Impact	61
Monitoring network design considerations.	61
Parameter selection	62
Sampling frequency.	69
Number and location of stations	75
Recommended Design.	81
References.	83
Appendix.	92

BEGIN
LAST LINE
OF TEXT

3/8"

vii

PAGE NUMBER

BOTTOM OF
IMAGE AREA,
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

FIGURES

<u>Number</u>		<u>Page</u>
Frontispiece	Decker Strip Mine and Tongue River Reservoir, Montana	
1	Western energy resource region	1
2	Coal resources in Montana, Wyoming, and western North and South Dakota	11
3	Coal resources in Utah, Colorado, and northern Arizona and New Mexico	12
4	Existing and proposed coal mines in the Yellowstone, Little Missouri, Belle Fourche, and North Platte River systems.	13
5	Existing and proposed coal mines in the San Juan, Colorado, and Green River systems.	14
6	Fossil fuel generating plants in the Yellowstone, Little Missouri, Belle Fourche, and North Platte River systems.	18
7	Fossil fuel generating plants in the San Juan, Colorado, and Green River systems.	19
8	Oil shale reserves in the Western United States.	21
9	Old oil pump showing leakage	23
10	San Juan River 1962 oil spill from ruptured pipeline	23
11	Uranium reserve regions, Western United States	25
12	Stack plume from coal-fired power plant emission	29
13	Uranium tailing pond failure	30
14	(A) Water supply truck (B) Oil from crankcase leak.	30
15	Number of samples vs. allowable error for selected standard deviations.	72
16	Recommended stations for monitoring western energy resource development impact on surface-water quality, Missouri River system	78
17	Recommended stations for monitoring western energy resource development impact on surface-water quality, Colorado River system	79

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

TABLES

<u>Number</u>		<u>Page</u>
1	Recommended Stations for Monitoring Western Energy Resource Development Impact on Surface-Water Quality.	5
2	Physical/Chemical Parameters to be Monitored for Assessment of Energy Resource Development Impact on Water Quality	6
3	Active and Planned Coal Mines in the Western Energy Resource Region	15
4	Minimum Estimates of Nonfuel Mineral and Material Requirements for Energy Production in the United States, 1975-90	31
5	Elemental Composition of Coal from a Number of Coal Fields Throughout the Western Energy Development Areas.	33
6	Average Effluent Concentrations from Western Coal Stockpiles . . .	35
7	Elemental Composition of Ashes from U.S. Coals	36
8	Maximum Concentrations of Elements in Various Water Samples. . . .	37
9	Trace Elements in Oil Shale Retort Waters and Spent-Shale Leachates.	40
10	Compounds and Organic Compound Classes Identified in Oil Shale and Coal Hydrogenation Process Streams and Products.	42
11	Observed Concentration Ranges of Organic Chemicals From Coal-Hydrogenation Streams and Waste-Water Removal Effectiveness. . .	43
12	Maximum Values of Semivolatile Organic Compounds Identified in Western Energy Resource Development Samples	44
13	Maximum Values of Volatile Organic Compounds Identified in Western Energy Resource Development Samples	49
14	Compounds Occurring More Than 15 Times at Concentrations of 100 ppb or More	54
15	Parameters Monitored by the Existing Sampling Network in the San Juan Basin and Their Average Annual Frequency of Measurement . .	57
16	High Priority Physical/Chemical Parameters and Parameters Presently Sampled at NASQAN Stations	64
17	STORET Data Statistics for Selected Parameters at Three Representative Stations.	73
18	NASQAN Station Descriptions.	80

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
LAST LINE
OF TEXT

3/8"

ix

PAGE NUMBER

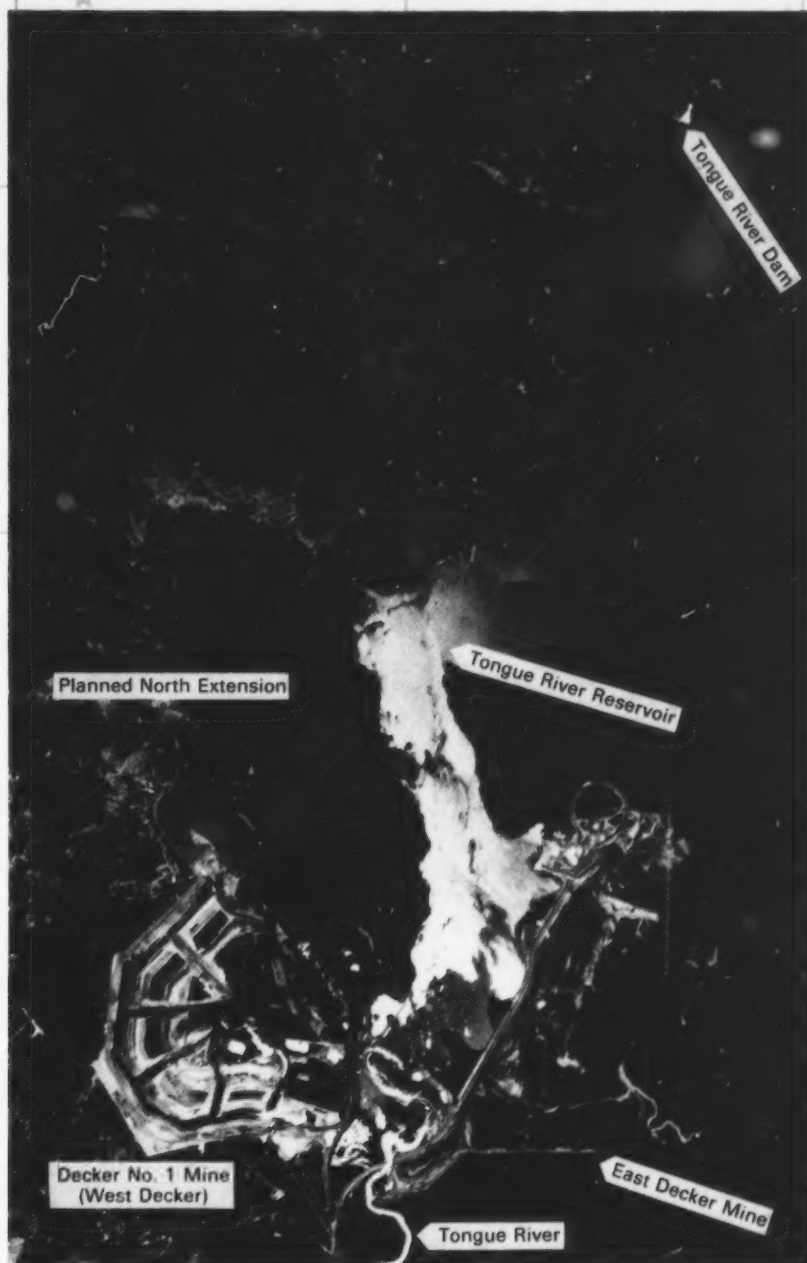
BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD.
BEGIN
SECTIONS
HERE



Frontispiece. Decker Strip Mine and Tongue River Reservoir, Montana. Although this is a well-planned facility, the potential for serious pollution to the reservoir from seepage or a spill exists because of the mine's size and proximity to the reservoir.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

INTRODUCTION

The United States has embarked on a program to reduce its dependency on foreign fuels. To accomplish this, large fossil fuel and uranium reserves located in the northern Great Plains and the Colorado Plateau (Figure 1) must be developed. These resources cannot be developed without some environmental disruption. However, close regulation and proper planning can minimize this disturbance and reduce it to tolerable levels.

The potential exists for serious environmental impact during exploitation of energy resources. Pollution of air, land, and water resources may occur during any or all of the necessary extraction, refining, transportation, conversion, and utilization processes. Secondary impacts from increased population pressures, water management, and development of supporting

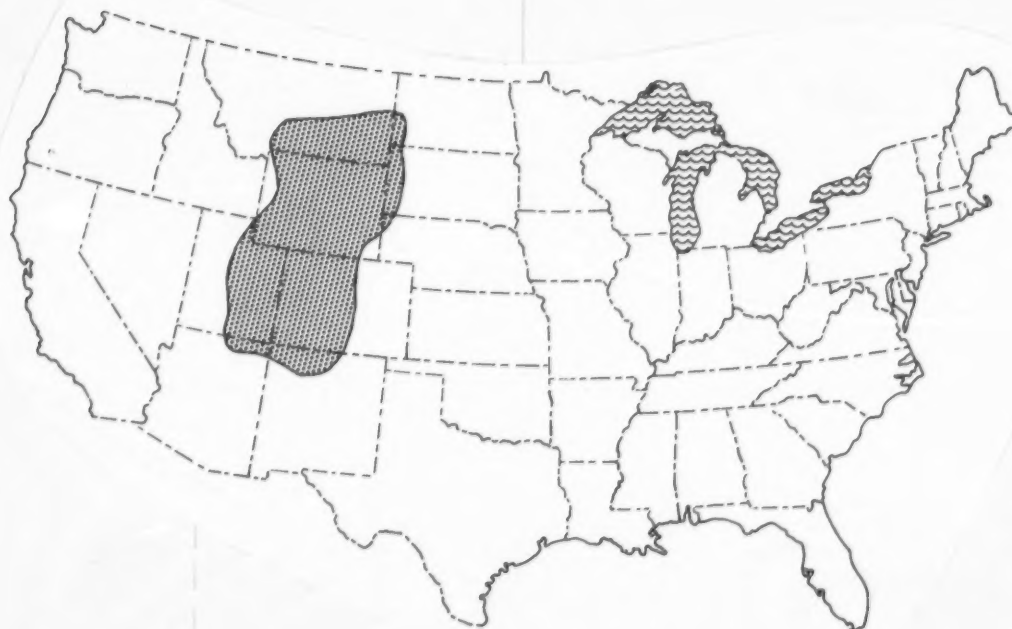


Figure 1. Western energy resource region.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

industries (e.g., cement manufacture, rail lines, etc.) promise additional environmental insults. Even the most closely controlled and well-planned development will have some impact; carelessly or improperly planned development could result in catastrophe.

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

In order to assess the impact of energy resource development in the western energy resource region, it is essential to develop a comprehensive monitoring program. The objective of this report is to describe a monitoring network that can be used to assess the impact of energy resource development on water quality in the western energy resource region. A monitoring network was selected which is designed to detect trends in surface-water quality. Biological, physical, and chemical parameters likely to be affected by energy resource development activities are identified. Radiological parameters were not included in this investigation because an existing network for radiological monitoring already exists.

The recommendations pertain to monitoring the impact of energy resource development on water quality in the Western Mountain States. They do not exclude the addition of other parameters to detect trends caused by other activities such as urban development, agricultural practices, etc. Neither do they exclude the operation of other stations or monitoring networks for other purposes; indeed, such activities are to be encouraged. The network design proposed herein is based upon knowledge and technology available today. As our understanding of the impacts, affected parameters, and stream modeling increases, and as technological innovations add to the monitoring instrumentation available, this design will necessarily be modified. These considerations, however, do not lessen the need for implementation of such a network at this time.

BEGIN
LAST LINE
OF TEXT

3/8"

2

PAGE NUMBER

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

CONCLUSIONS

The following conclusions have been reached regarding the monitoring of energy resource development impact upon western water quality:

1. Western energy resource development has great potential for degrading the quality of both surface and ground waters. Water quantity will be affected more severely than water quality, but consumptive use imposes its own effect on water quality. In addition, modern technology will produce large quantities of toxic and carcinogenic chemicals that could have subtle, but devastating, environmental impact.

2. Existing water-quality monitoring activities are inadequate to detect subtle trends in many water-quality parameters over relatively short (<5 years) time periods.

3. Ground-water monitoring networks are only now being implemented. Past survey data are useful only in determining baseline conditions or investigating specific local problems.

4. Impact assessment may best be accomplished by monitoring to detect short-term (2 to 4 years) trends in water-quality parameters likely to be affected by energy resource development activities. (This should not be confused with monitoring for only 2 to 4 years.) This trend period is adequate to identify short-term effects from activities such as road construction near the river, one-year droughts, etc. and will permit identification of activities likely to pose a problem in the future. It will also permit detection of small-magnitude changes in observed concentrations.

5. Existing monitoring stations, especially National Stream Quality Accounting Network (NASQAN) stations, are suitably located for monitoring trends in energy resource development impact on surface-water quality. Ground-water monitoring networks are only now being established.

6. A minimum monitoring frequency between 7 and 14 days is necessary to obtain satisfactory statistical precision for assessing most parameters.

7. Trend monitoring can only detect changes in water quality; it cannot determine the causes for those changes. Data from trend-monitoring stations must be augmented by data from other stations and from intensive surveys in order to determine causes for discerned trends.

BEGIN
LAST LINE
OF TEXT

8. Monitoring on a regular basis for the large number of organic compounds that may be released into the environment is not cost-effective.

3/8"

3

PAGE NUMBER

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

The impact of these, and other perturbations, may be assessed through biological monitoring. However, techniques are not well developed and need further research. In particular, techniques need to be developed to assess the impact on biota of numerous potential carcinogenic compounds present in minute quantities. In addition to laboratory studies (assays, etc.), monitoring techniques that use naturally occurring populations are needed in order to provide an early warning for human exposure.

9. Trend monitoring for energy resource development impact can also provide data on trends caused by other activities (e.g., agriculture, recreational development, etc.) in energy resource areas.

6 1/2"

9 1/8"

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

4

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

RECOMMENDATIONS

A water-quality trend-monitoring network consisting of relatively few stations with increased sampling frequencies is recommended to assess the impact of western energy resource development on surface-water quality. This would permit the detection of trends in water quality over a 2- to 4-year period.

Twenty-five existing stations should be included in this network (Table 1). Seventeen existing NASQAN stations and eight other USGS stations are located in downstream reaches of rivers draining areas where energy resources are located and development activities have begun.

TABLE 1. RECOMMENDED STATIONS FOR MONITORING WESTERN ENERGY RESOURCE DEVELOPMENT IMPACT ON SURFACE-WATER QUALITY

USGS Station Number	Description
09380000	Colorado River at Lees Ferry, Ariz.
09368000	San Juan River at Shiprock, N. Mex.
09379500	San Juan River near Bluff, Utah
09180500	Colorado River near Cisco, Utah
09152500	Gunnison River near Grand Junction, Colo.
09132500*	North Fork Gunnison River near Somerset, Colo.
09217000*	Green River near Green River, Wyo.
09224700*	Blacks Fork near Little America, Wyo.
09251000	Yampa River near Maybell, Colo.
09260000	Little Snake River near Lily, Colo.
09306500*	White River near Watson, Utah
09306222*	Piceance Creek at White River, Colo.
09314500*	Price River at Woodside, Utah
09328500*	San Rafael River near Green River, Utah
09315000	Green River at Green River, Utah
06635000*	Medicine Bow River above Seminoe Res., Wyo.
06438000	Belle Fourche River near Elm Springs, S. Dak.
06337000	Little Missouri River near Watford City, N. Dak.
06130500	Musselshell River at Mosby, Mont.
06214500	Yellowstone River at Billings, Mont.
06294700	Bighorn River at Bighorn, Mont.
06308500	Tongue River at Miles City, Mont.
06326500	Powder River near Locate, Mont.
06329500	Yellowstone River near Sidney, Mont.
08251500	Rio Grande River near Lobatos, Colo.

BEGIN
LAST LINE
OF TEXT

*Not NASQAN stations

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

Sampling for most parameters should be conducted routinely every 8 to 13 days at each station. Continuous monitoring of flow, conductivity, pH, and temperature is recommended with data subsequently reduced to daily mean values. Sampling and analysis of sediment samples should be on a quarterly basis. Table 2 lists physical and chemical parameters that should be routinely monitored. It is recommended that all water-quality parameters be monitored at all network stations.

Biological monitoring is the most direct monitoring technique for assessment of energy resource development impact. Biological monitoring techniques should be developed, especially those utilizing natural stream populations to assess subtle, long-term effects. Biochemical uptake and periphyton sampling and analysis should be immediately implemented. Collection and storage of other biological samples for future analysis is also highly recommended.

TABLE 2. PHYSICAL/CHEMICAL PARAMETERS TO BE MONITORED FOR ASSESSMENT OF ENERGY RESOURCE DEVELOPMENT IMPACT ON WATER QUALITY

Alkalinity, total	Kjeldahl nitrogen
Aluminum, dissolved	Lead, total*
Ammonia - nitrogen	Magnesium, dissolved
Arsenic, total*	Molybdenum, total*
Barium, total*	Nickel, total*
Biochemical oxygen demand, 5-day*	Nitrate nitrogen
Bicarbonate, dissolved	Nitrite nitrogen
Boron, total	Oxygen, dissolved
Carbon, dissolved organic	Oil*
Carbon, total organic*	pH
Cadmium, total	Phenols*
Calcium, dissolved	Sediment grain size
Carbonate, dissolved	(sediment samples only)
Chloride, dissolved or ionic	Selenium, total*
Chromium, total*	Sodium, dissolved
Coal content	Solids, total suspended
(sediment samples only)	Solids, total dissolved
Conductance, specific@25°C	Sulfate, dissolved
Copper, total*	Temperature
Cyanide, total*	Turbidity
Flow	Uranium, total*
Fluoride, dissolved	Vanadium, total*
Iron, total*	Zinc, total*

*Measure in sediment samples also.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

BACKGROUND

With the development of the "energy crisis," the fossil fuel reserves of the Western United States suddenly gained increased importance. Throughout the 1950's, the United States was effectively energy self-sufficient, satisfying its needs with abundant reserves of domestic fuels such as coal, oil, gas, and hydroelectric power. However, energy consumption has been increasing during the past 10 years at an annual rate of 4 to 5 percent, a per capita rate of consumption eight times that of the rest of the world (U.S. Bureau of Reclamation 1977a). The Federal Energy Administration (1974) in its "Project Independence" report states:

By 1973, imports of crude oil and petroleum products accounted for 35 percent of total domestic consumption.

Domestic coal production has not increased since 1943.

Exploration for coal peaked in 1956, and domestic production of crude oil has been declining since 1970.

Since 1968, natural gas consumption in the continental United States has been greater than discovery.

The United States now relies on oil for 46 percent of its energy needs, while coal, our most abundant domestic fossil fuel, serves only 18 percent of our total needs (U.S. Bureau of Reclamation 1977a). Foreign oil imports have risen from \$3 billion to \$45 billion in six years (1971 to 1977) and are the largest contributor to the U.S. trade deficit (Hayes 1979). To reduce the United States vulnerable economic and military dependency on foreign oil, the Federal government is promoting the development of untapped national energy resources. Included among these resources are the abundant western energy reserves. Over half of the Nation's potential coal and effectively all the potential uranium, oil shale, and geothermal resources are located in the Western United States (Harza Engineering Company 1976).

Western energy resources are located primarily in a belt along the Rocky Mountains and Colorado Plateau extending from the Northern Great Plains (Montana, North and South Dakota, and Wyoming) into Arizona and New Mexico (Figure 1). This region is characterized by sparse annual rainfall, generally less than 50 centimeters (cm) per year except at higher elevations (Geraghty et al. 1973). Annual surface-water runoff is less than 3 cm over most of the area. Numerous mountain streams rapidly combine into larger rivers or disappear into desert sands. Flows are erratic, with maximum flows generally occurring during the snowmelt period, April to July. Episodic storms can result in substantial discharge and flooding, especially in local areas. At

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

7

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

lower elevations most small streams are intermittent or ephemeral in nature. In this water sparse region, energy resource development will have an impact on both water quality and quantity.

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

Water resources are highly managed in order to provide dependable, year-round supplies. In 1965 more than 580 reservoirs with capacities greater than 61,000 cubic meters (m^3) and more than 40 transmountain diversions existed in the Upper Colorado River Basin alone (Water Resources Work Group 1971). Evaporation from these impoundments ranges from 75 cm to about 150 cm per year and is second only to agriculture as a consumptive user of water in the region.

Water rights in this semiarid region are based largely on the appropriation doctrine. The doctrine has two fundamental principles: (1) first in time is first in right, and (2) beneficial water use is the basis of that right. According to Gould (1977), appropriation of water rights is controlled by the States through permits and generally proceeds in five steps: (1) declaration of an intent to appropriate water; (2) notification to others of this intent; (3) compliance with prescribed State formalities; (4) diversion of water; and (5) application of the water to beneficial water use. Historically, the requirement of diversion essentially ruled out any basic instream flow rights over and above those necessary to supply downstream appropriations. Recently, however, both legislative actions and court rulings have recognized that minimum flows to maintain fisheries are bona fide beneficial uses and that diversions are not required to establish water rights (Gould 1977; Cox and Walker 1977).

The impact of this departure from historical appropriation doctrine is immense, particularly in areas where water rights are already over-appropriated. Shupe (1978) conducted computer simulations of potential reservoirs and proposed instream flow requirements in the Powder River Basin. He found that instream flow requirements necessitated continuous discharge of a portion of the storage capacity of reservoirs and reduced water availability for industrial use 53 to 86 percent. An assessment of the planned Middle Fork (of the Powder River) Reservoir found that without instream flow criteria the reservoir would be capable of providing $53 \times 10^6 m^3$ of water annually on a constant withdrawal basis. With the instream flow requirements implemented, he found that the reservoir would operate nearly empty much of the time and could only provide $20 \times 10^6 m^3$ of water annually for diversion.

Ground-water resources, although substantial in the study area, are limited geographically (U.S. Geological Survey 1970) and often are of poor quality. Sufficient and suitable ground water is unavailable in many areas of exploitable energy resources, thus increasing the importance of surface water (University of Oklahoma and Radian Corporation 1977).

Water rights to both surface-and ground-water supplies are further complicated by Federal and Indian claims, interstate compacts, conflicting legal decisions, and the rapid disappearance of unallocated waters (Native American Natural Resources Development Federation of the Northern Great Plains 1974). Changing social outlooks with increased emphasis on aesthetic and recreational considerations are also of importance (Cox and Walker 1977).

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

8

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

Energy resource development is anticipated to be a large consumptive user of water, especially on the local level, and production will ultimately be limited by available supplies in many areas.

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD.
BEGIN
SECTIONS
HERE

ENERGY RESOURCE DEVELOPMENT

COAL

Energy resource development in the western energy resource region will be predominantly the exploitation of coal reserves (Figures 2 and 3) and construction of coal-fired powerplants (University of Oklahoma and Radian Corporation 1977). Figures 4 and 5 and Table 3 indicate the extent and nature of major ongoing and planned coal mining activities in the Rocky Mountain region. Many of these mines are tied to the development of coal gasification or liquefaction plants. Established markets exist for the Rocky Mountain region's abundant low-sulfur coal in local, Midwest, and Southwest coal-fired generating plants. There is active construction of many new plants in the Western States. In 1976 a total of 488 new generating units were planned for States west of the Mississippi (Corsentino 1976), of which about 20 percent were planned for the study area. Locations of present and proposed fossil-fuel electrical generating plants in the study area are shown in Figures 6 and 7.

Figures 4 through 7 indicate that the development of coal and coal-fired powerplants largely occurs in clusters. The Colstrip-Sheridan area, the Gillette area and its southward extension, the Seminole Reservoir region, the Rock Springs and Naughton areas, the White-Yampa River region, the Gunnison area, the Huntington Canyon area, and the San Juan Basin area are concentrations of coal-mining and powerplant development. Figures 4 and 5 and Table 3 show that nearly all coal exploitation is strip mining in the Montana and Wyoming regions. As one moves south into Colorado, increased numbers of underground mines are found. In the Gunnison and Huntington Canyon areas, mining operations are primarily underground. Mines along the Utah-Arizona and Colorado-New Mexico borders are primarily strip mines, except near Raton where underground mines are common.

Coal liquefaction is also planned. Corsentino (1976) lists 22 proposed plants. Commercial development has been slow, and significant development of liquefaction facilities is not now anticipated prior to 1985. Liquefaction plants will probably be located near coal mines in areas where sufficient water is available (Gold and Goldstein 1978).

Strip mining and surface disposal of wastes may have impact on visual aesthetics. In addition, the disruption of natural surfaces may lead to increased erosion and loading of nearby streams with suspended sediments and may remove land from agricultural or other uses. Poor spoil-pile disposition may lead to unstable and potentially catastrophic situations. Disruption of soil and rock layers exposes fresh surfaces to chemical weathering and results in greatly increased dissolved solids concentrations in both surface and ground waters.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

Anthracite, medium - and high-volatile bituminous coal Beds of commercial value at present	Subbituminous Coal Beds of commercial value at present	Lignite and Brown Coal Beds of commercial value at present
Areas of doubtful commercial value	Areas of doubtful commercial value	Areas of doubtful commercial value

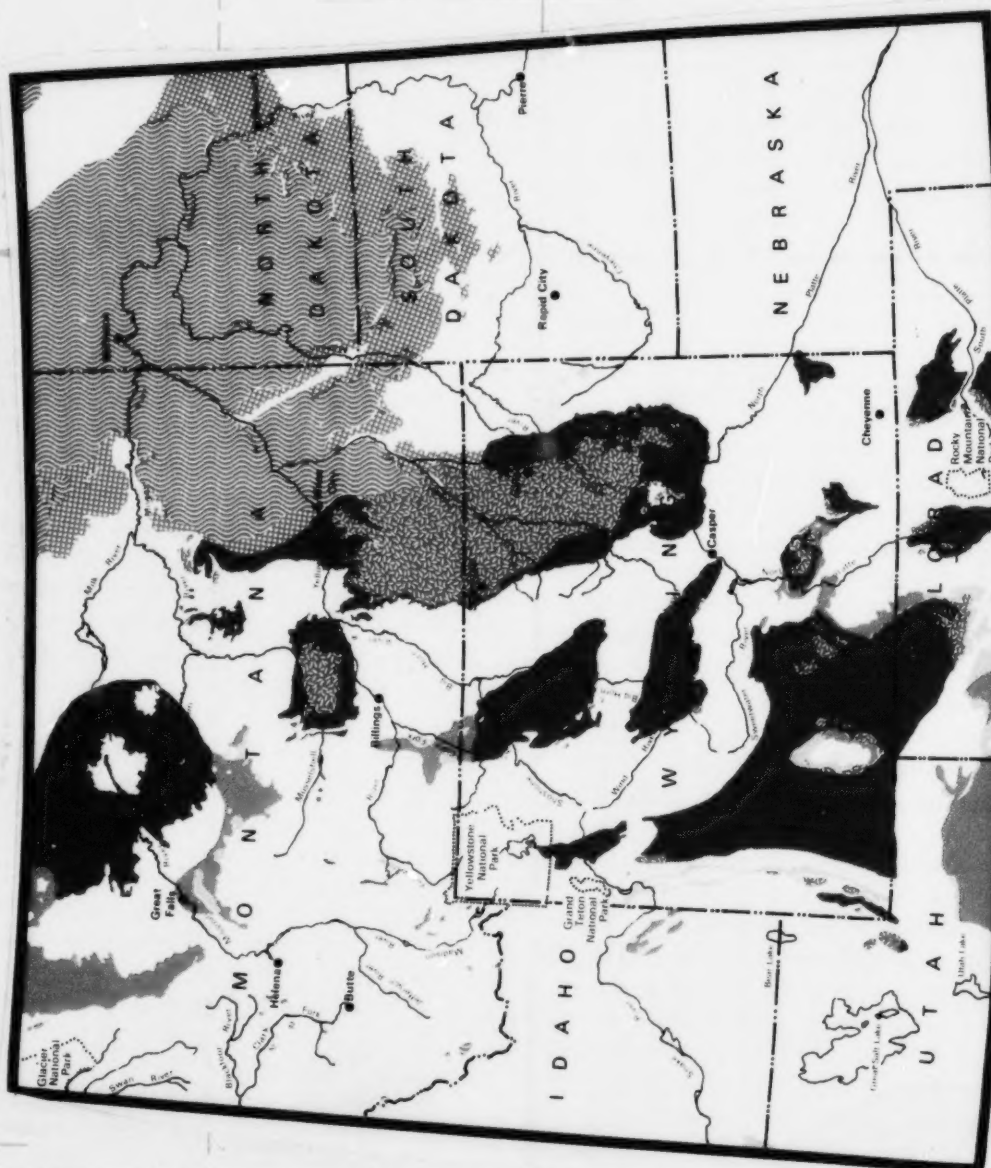


Figure 2. Coal resources in Montana, Wyoming, and western North and South Dakota
(from Trumbull 1960).

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

**Anthracite, Medium
- and High-Volatile
Bituminous Coal**
Beds of commercial
value at present

Areas of doubtful
commercial value

Subbituminous Coal
Beds of commercial
value at present

Areas of doubtful
commercial value

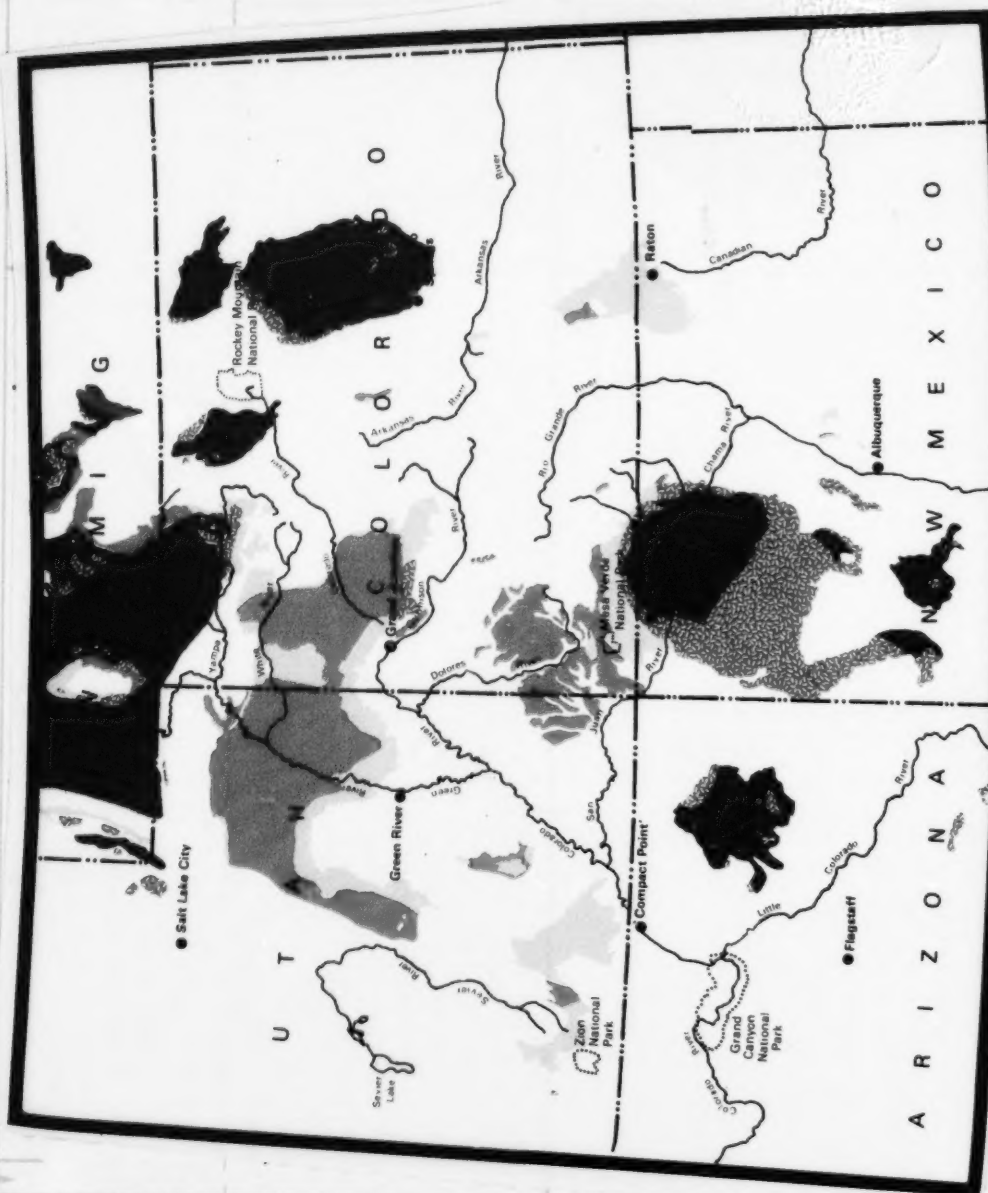


Figure 3. Coal resources in Utah, Colorado, and northern Arizona and New Mexico
(from Trumbull 1960).

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
LAST LINE
OF TEXT

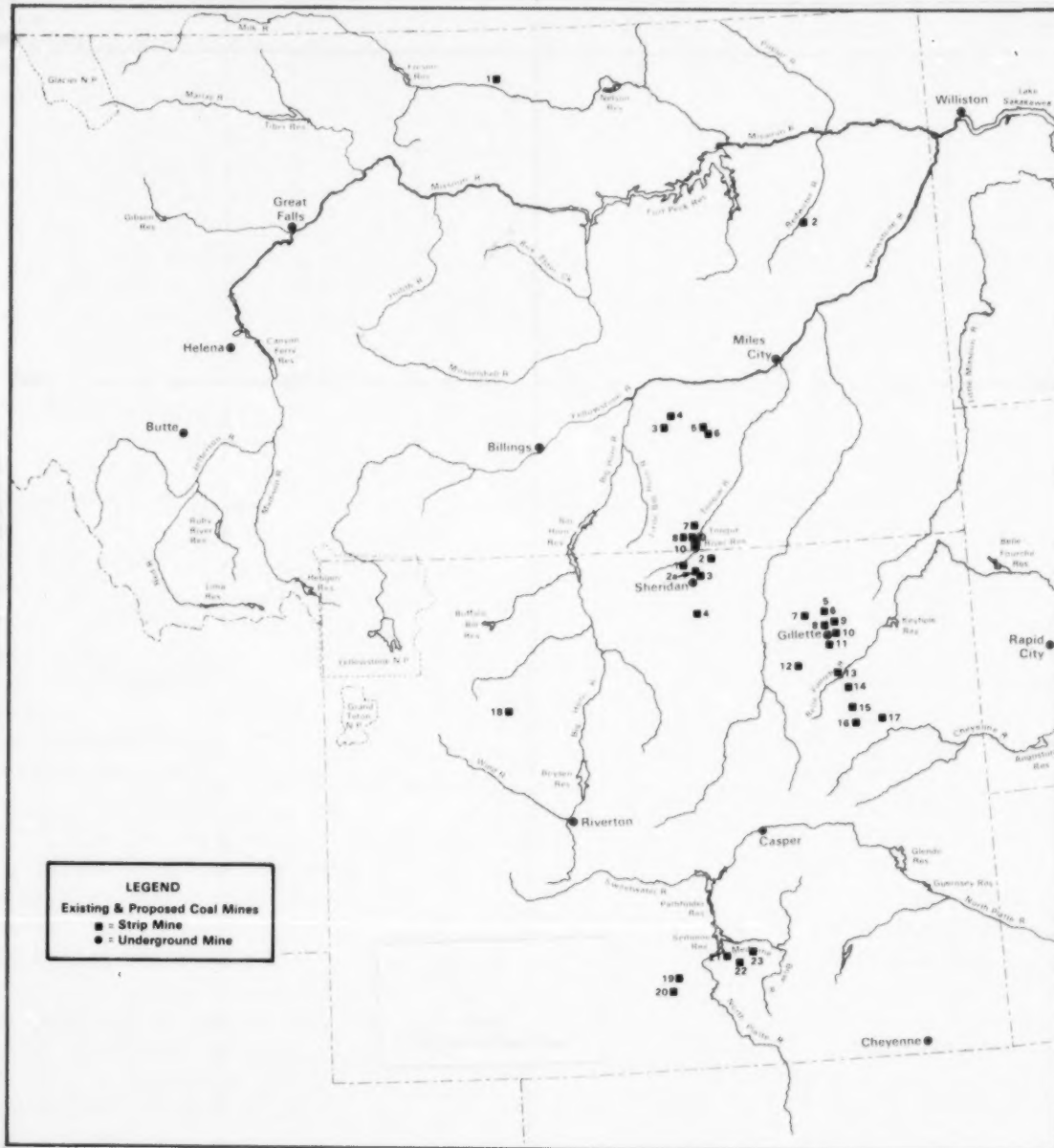
BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTION
HERE



BEGIN
LAST LINE
OF TEXT

Figure 4. Existing and proposed coal mines in the Yellowstone, Little Missouri, Belle Fourche, and North Platte River systems (Corsetino 1976; U.S. Environmental Protection Agency).

BOTTOM OF
IMAGE AREA,
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

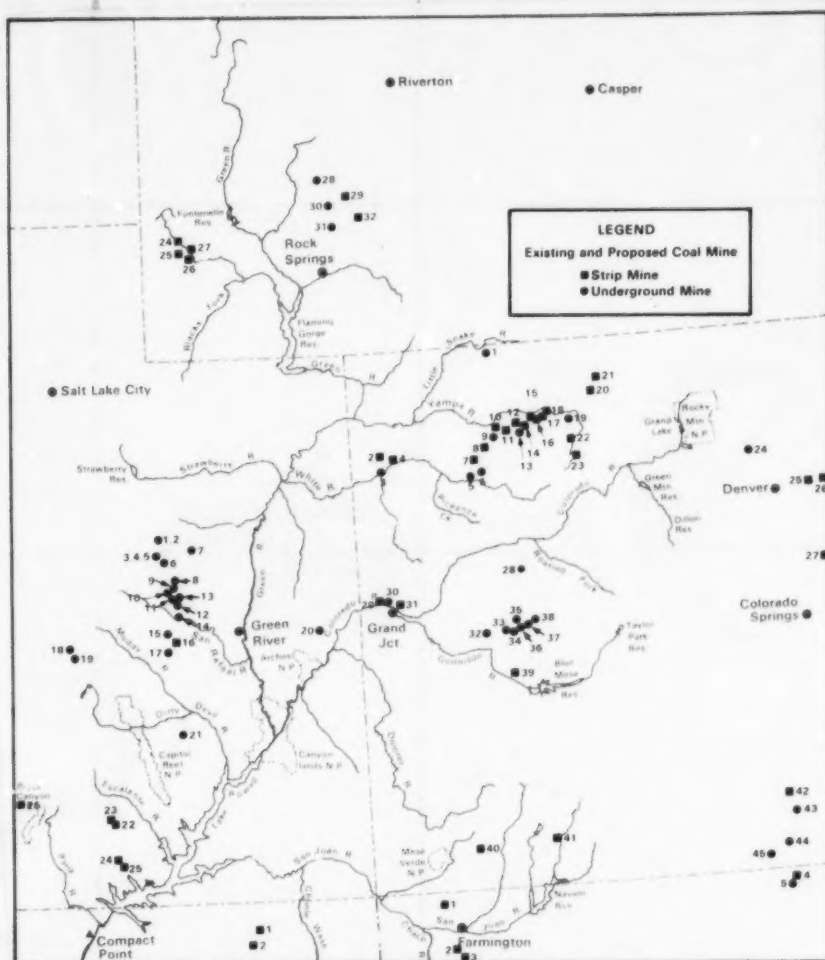


Figure 5. Existing and proposed coal mines in the San Juan, Colorado, and Green River systems.

A frequently cited 1973 study by Van Voast of well water collected on the same day from an unmined area and from an area with overlying old coal spoil materials is a dramatic example (Harza Engineering Corporation 1976). The calculated dissolved solids level in ground water beneath the spoils was more than three times that in the undisturbed area. In the spoils area, levels of magnesium were seven times those in the undisturbed area; calcium, sulfate, and iron levels nine times; and nitrate and manganese fifteen times. Slight decreases in sodium and bicarbonate concentrations were observed. Contaminated ground water may move through an aquifer and may reach a stream or river.

The chemical composition of the coal bed, the overlying rock strata and soils, and the amount and nature of their exposure to water influence the

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 3. ACTIVE AND PLANNED COAL MINES IN THE WESTERN ENERGY RESOURCE REGION

DROPPED
HEAD
BEGIN
SECTION
HERE

Mine No. from Figs. 4 and 5	Mine Name	Type*	Owner	Status/ Operational Date	Market	Maximum Output (10 kg/year)	Remarks
MONTANA							
1	McCartney	(s)	Clay & McCartney	-	-	?	-
2	Savage Mine	(s)	Knife River Coal Co.	Existing	Local	0.3	-
3	Circle West	(s)	Dryer Bros.	New/1980	Circle West Ammonia Plant and possible coal liquefaction	27.2	-
4	Sarpy Creek (Absaloka)	(s)	Westmoreland Resources	Exp/1980	Northern midwestern P.P.	137.9	-
5	East Sarpy Creek	(s)	Amax Coal Co.	-	-	?	-
6	Rosebud Mine	(s)	Western Energy Co.	Exp/1980	Colstrip P.P.	173.3	-
7	Big Sky Mine	(s)	Peabody Coal Co.	Exp/1977	Minnesota P & L	24.5	-
8	Spring Creek Mine	(s)	Pacific Power & Light	-	-	-	Proposed
9	Young Creek, Tanner Creek	(s)	Shell Oil	New/1980	-	145.1	-
10	Decker Mines		Decker Coal Co.	Exp/1979	Austin Texas, Commonwealth Edison P.P., Detroit, Mich. Edison P.P.	49.9	-
WYOMING							
1	PSO Mine	(s)	Public Service of Oklahoma	New/1978	Oklahoma P.P.	4.5	-
2	Whitney	(s)	Peter Kiewit Sons, Inc.	New/?	-	?	Proposed
2a	Welch Strip	(s)	Welch Coal Co.	Existing	Acme P.P., Sheridan, Wyo.	0.2	-
3	Big Horn	(s)	Big Horn Coal Co.	Exp/1980	Midwestern powerplants	13.6	-
4	Lake De Smet	(s)	Texaco, Inc.	New/?	Coal gasification plant	?	Proposed
5	Buckskin Mine	(s)	Shell Oil Co.	New/1980	Shell Oil, Houston refinery	36.3	Proposed
6	North Rawhide	(s)	Carter Mining Co.	New/1976	Midwestern utilities	77.1	-
7	Unnamed nr Felix	(s)	Falcon Coal Co.	New/?	-	2.7	Proposed
8,13	Belle Ayr (North & South)	(s)	Amax Coal Co.	Exp/1980	Midwest, Southwest, and Pacific Northwest P.P.	90-136	-
9	East Gillette	(s)	Kerr McGee	New/1977	Ark., La., and Okla. utilities	45-100	-
10	Wyodak	(s)	Wyodak Resources Devel.	Exp/1980	Wyodak P.P.	20.0	-
11	Caballo	(s)	Carter Oil Co.	New/1980	-	18-45	Proposed
12	Thunderbird	(s)	El Paso Natural Gas Co.	New/1979	P.P.	27.2	Proposed
14	Cordero	(s)	Sunoco Energy Devel.	New/1981	San Antonio Public Service P.P. and Tri-State P.P. @ Wheatland	108.9	-
15	Jacobs Ranch	(s)	Kerr McGee	New/1978	Ark., La., and Okla. utilities	122.0	-
16	Black Thunder	(s)	Atlantic Richfield	New/1980	Midwestern P.P.	63-91	-
17	Rochelle	(s)	Peabody Coal	New/1980	Proposed coal gasification plant	45-100	Proposed
18	Grass Creek	(s)	Northwestern Resources	Exp/1980	-	6.4	-
18a	Dave Johnson Mine	(s)	Pacific Power & Light	Existing	Dave Johnson P. P.	24.5	Proposed
19	Red Rim	(s)	Rocky Mt. Energy Co.	New/1980	Iowa Public Service	22.7	-
20	China Butte	(s)	Rocky Mt. Energy Co.	New/1980	-	9-27	-
21	Medicine Bow	(s)	Medicine Bow Coal Co.	Exp/1980	North Indiana Public Service Co.	32.7	-
22	Vanguard #2 & 3	(u)	Energy Development Co.	Exp & New/1980	Iowa Public Service P.P.	9-181	-
23	Hanna	(u)	Rocky Mountain Energy Co.	New/1980	P.P.	22.7	-
24	Sorenson	(s)	Kemmerer Coal Co.	Exp/1980	Naughton P.P.	27-43	-
25	Elkol	(s)	Kemmerer Coal Co.	Exp/1980	Allied Chem., Almagamated Sugar	10.0	-
26	FMC Mine	(s)	FMC Corp.	Exp/1980	FMC Trona Plant	9-18	-
27	Twin Creek	(s)	Rocky Mountain Energy Co.	New/1980	-	27.2	-
28	Long Canyon	(u)	Rocky Mountain Energy Co.	New/?	-	?	-
29	Bridger	(s)	Bridger Coal Co.	Exp/1980	Jim Bridger P.P.	68.0	-
30	Stansbury #1	(u)	Stansbury Coal Co.	New/1980	Ideal Cement	12.7	-
31	Rainbow #8	(u)	Columbine Mining Co.	Exp/1980	Mine Mouth Coke Plant	1.8	-
32	Black Butte	(s)	Black Butte Coal Co.	New/1977	Idaho Power Co.	49.2	-

(continued)

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
LAST LINE
OF TEXT

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 3. (Continued)

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

Mine No. from Figs. 4 and 5	Mine Name	Type*	Owner	Status/ Operational Date	Market	Maximum Output (10 kg/year)	Remarks
UTAH							
1	Brazath #3,4,5,6	(u)	Brazath Corp.	Exp/1980	Indiana-Michigan Electric Co. & other midwestern P.P.	59.0	-
2	Gordon Creek #3	(u)	General Exploration Co.	New/1977	Local and out-of-state commercial	1.8	-
3	Utah #2	(u)	Valley Camp of Utah	New/1977	Midwestern and western commercial	6.4	-
4	Belina #1 & 2	(u)	Valley Camp of Utah	New/1977	Midwestern and western commercial	19.1	-
5	O'Conner #1	(u)	Valley Camp of Utah	New/1977	Midwestern and western commercial	1.8	-
6	Star Point #3	(u)	Plateau Mining Co.	New/1977	Rocky Mountain states	9.1	-
7	Unnamed nr Sunnyside	(u)	Island Creek Coal Co.	New/1977	California P.P.	18.1	-
8	Deer Creek	(u)	Peabody Coal Co.	Exp/1977	Huntington Canyon P.P.	22.7	-
9	Swisher #5	(u)	Swisher Coal Co.	New/1978	Local and out-of-state commercial	1.8	Reopen old mine
10	Soldier Canyon	(u)	California Portland Cement Co.	Exp/1977	California Portland Cement plants	9.1	-
11	Huntington Canyon #4	(u)	Swisher Coal Co.	New/1978	Local and out-of-state commercial	1.8	Reopen old mine
12	Rilda Canyon	(u)	Western American Energy Corp.	New/?	-	1.8	Proposed
13	Wilberg	(u)	Peabody Coal Co.	New/1980	-	20.0	-
14	Emery	(u)	Consolidation Coal Co.	Exp/1980	Commercial & P.P.	12.7	-
15	Straight Canyon	(u)	Utah Power & Light Co.	New/1980	North Emery P.P.	22.7	-
16	Emery Strip	(s)	Consolidation Coal Co.	New/?	Commercial & P.P.	4.5	Proposed
17	Ferron Canyon	(u)	Inspirational Development Co.	New/1980	-	4.5	Proposed
18	South Utah Fuels #1	(u)	Constal State Energy Co.	Exp/1977	South Utah markets	13.6	-
19	Unnamed Sevier County	(u)	Clinton Oil Co.	New/1980	Commercial	9.1	-
20	Thompson Mine	(u)	Western American Energy Corp.	New/?	-	1.8	Proposed
21	Int. Power Project Mines		ICPA	New/1985	Factory Butte P.P.	90.7	-
22	Escalante	(u)	Utah Power & Light Co.	New/1981	Garfield P.P.	54.4	Proposed
23	Factory Butte	(s)	Atlas Minerals	New/1977	Power generators	9.1	-
24	Kaiparowits	(u)	Kaiser Industries	New/1984	Kaiparowits P.P.	90.7	Plans discontinued for present
25	John Henry Mine	(u)	SM Corp.	New/1977	-	3.6	-
26	Unnamed nr Alton	(u)	Nevada Power Co.	New/1982	P.P. in St. George, Utah and Las Vegas, Nev.	104.3	-

COLORADO

1	Unnamed nr Savory	(u)	Kemmerer Coal Co.	-	-	?	Proposed
2	Unnamed nr Rangely	(s&u)	Blue Mountain Coal	-	Export	?	Proposed
3	Gordon Mine	(u)	Moon Lake Elec. Co.	New/?	Mine-mouth P.P. for oil shale development	20.9	-
4	Unnamed nr Rangely	(s)	Midland Coal Co.	New/1981	-	1.8	-
5	Rienau #2	(u)	American Fuels, Inc.	Exp/1980	Local	2.7	-
6	Unnamed nr Meeker	(u&s)	Consolidation Coal Co.	New/1981	-	39.9	-
7	Colowyo	(s)	W. R. Grace	Exp/1979	Out-of-state utilities	27.2	-
8,16	Unnamed nr Craig	(s)	Paul S. Coupey	New/1980	-	9.1	Proposed
9	Wise Hill #5,6, & 7	(u&s)	Empire Energy Corp.	Exp/1980	F & I Steel and out-of-state markets	18.0	-
10	Unnamed nr Craig	(s)	Utah Int., Inc.	New/1980	Craig P.P.	26.3	-
11	Wilson Creek Mine	(s)	Utah Int., Inc.	-	Craig P.P.	?	Proposed
12	Unnamed nr Pagoda	(s)	Amer. Elec. Power System	New/1981	AEP P.P. eastern U.S.	12.7	-
13	Sun Mine	(u)	Ruby Construction	New/1977	In-state markets	2.7	-
14	Seneca 2-W	(s)	Peabody Coal	Exp/1977	Hayden P.P.	7.3	-

(continued)

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

TABLE 3. (Continued)

Mine No. from Figs. 4 and 5	Mine Name	Type*	Owner	Status/ Operational Date	Market	Maximum Output (10 kg/year)	Remarks
15	Unnamed nr Steamboat Springs	(u)	Coal Fuels	New/1977	-	18.1	-
17	Unnamed nr Steamboat Springs	(s)	Thomas C. Woodward	New/1980	-	39.9	-
18	Unnamed nr Steamboat Springs	(s)	Merchants Petroleum Co.	New/1980	-	39.9	-
19	Unnamed nr Steamboat Springs	(s)	Morgan Coal Co.	-	-	-	Proposed
20	Unnamed nr Walden	(s)	Consolidation Coal Co.	New/1979	-	9.1	-
21	Grizzly Creek	(s)	Sunflower Energy Corp.	Exp/1980	Electric utilities	18.1	-
22	Energy #1 & 2	(s u)	Energy Fuels Corp.	Exp/1980	Public service of Colorado P.P.	40.8	-
23	Edna Mine	(s)	Pittsburgh & Midway Coal Company	Exp/1980	-	10.1	-
24	Lincoln Mine	(u)	Adolph Coors Co.	New/1976	Coors Ind.	1.8	-
25	Watkins Lignite	(s)	Cameron Engineers	New/1983	Mine-mouth gasification	90.7	High un- certainty
26	Unnamed nr Watkins	(s)	Kerr McGee	-	Gasification	-	High un- certainty
27	Station Creek	(s)	Cameron Engineers	New/1980	Industrial fuel	9.1	-
28	Thompson Creek #1 & 3	(u)	Anschutz Coal Co.	Exp/1979	Steel mills	9.1	Reopen old mine
29	McKinley #1	(u)	Energy & Export Co.	New/1977	-	0.9	-
30	McKinley Mine	(u)	Eagle Head Coal Co.	New/1976	-	2.3	-
31	CMC Mine	(u)	Cambridge Mining Corp.	Exp/1977	Cameo P.P.	17.2	-
32	Coalby #2	(u)	Coalby Mining Co.	Exp/1978	-	-	-
33	King Mine	(u)	Adolph Coors Co.	New/1980	Coors Ind.	4.5	Reopen old mine
34	Old Blue Ribbon Mine	(u)	Sunflower Energy Corp.	Reopening/ 1977	Local	0.9	-
35	Converse Mine	(u)	Colorado Westmoreland	Exp/1980	Midwestern utilities	13.6	-
36	Farmers Mine	(u)	Pittsburgh & Midway Coal Company	Exp/?	-	9.1	-
37	Unnamed nr Somerset	(u)	Atlantic Richfield	New/1980	Electric utilities in west- ern Colorado or eastern Utah	18.1	-
38	Hawks Nest East	(u)	Western Slope Carbon, Inc.	Exp/1977	CF & I Steel, Pueblo, Colo.; Ford Motor Co., Detroit, Mich.	5.4	-
39	Unnamed nr Cimarron	(s)	H.W. Siddle	-	-	-	Proposed
40	Unnamed nr Hesperus	(s)	Energy Resources, Ltd.	New/?	-	-	-
41	Mel Martinez Mine	(s)	Milton Fuller	Exp/1978	New Mexico markets	2.3	-
42	Unnamed nr Walsenburg	(s)	Groves/Calder	-	Local	-	Proposed
43	Unnamed nr Pryor	(u)	Tipperary Oil & Gas Corp.	New/1978	-	4.5	-
44	Maxwell	(u)	CF & I Steel Corp.	New/1978	CF & I Steel Pueblo, Colo.	5.4	-
45	Lorencito	(u)	Freeport Coal co.	New/1979?	Eastern steel mills	9.1	-
ARIZONA							
1	Kayenta	(s)	Peabody Coal Co.	Exp/1977	Navajo P.P.	72.6	-
2	Black Mesa Mine	(s)	Peabody Coal Co.	Exp/1977	Mohave P.P.	45.4	-
NEW MEXICO							
1	San Juan Mine	(s)	Utah Int., Inc.	Exp/1980	San Juan P.P.	52.6	-
2	Navajo Mine	(s)	Utah Int., Inc.	Exp/?	WESCO Gasification, Navajo and 4 Corners P.P.	371.9	-
3	Burnham Complex Mine	(s)	Consolidation Coal Co.	New/?	Burnham Coal Gasification Complex	26.8	-
4	West York Strip	(s)	Kaiser Steel Corp.	Exp/1976	Fontana, Calif., steel mill	4.5	-
5	York Canyon #1	(u)	Kaiser Steel Corp.	Exp/1977	Fontana, Calif., steel mill	6.4	-

(s) = Strip mine
(u) = Underground mine
P.P. = Powerplants

BEGIN
LAST LINE
OF TEXT

3/8"

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTION
HERE

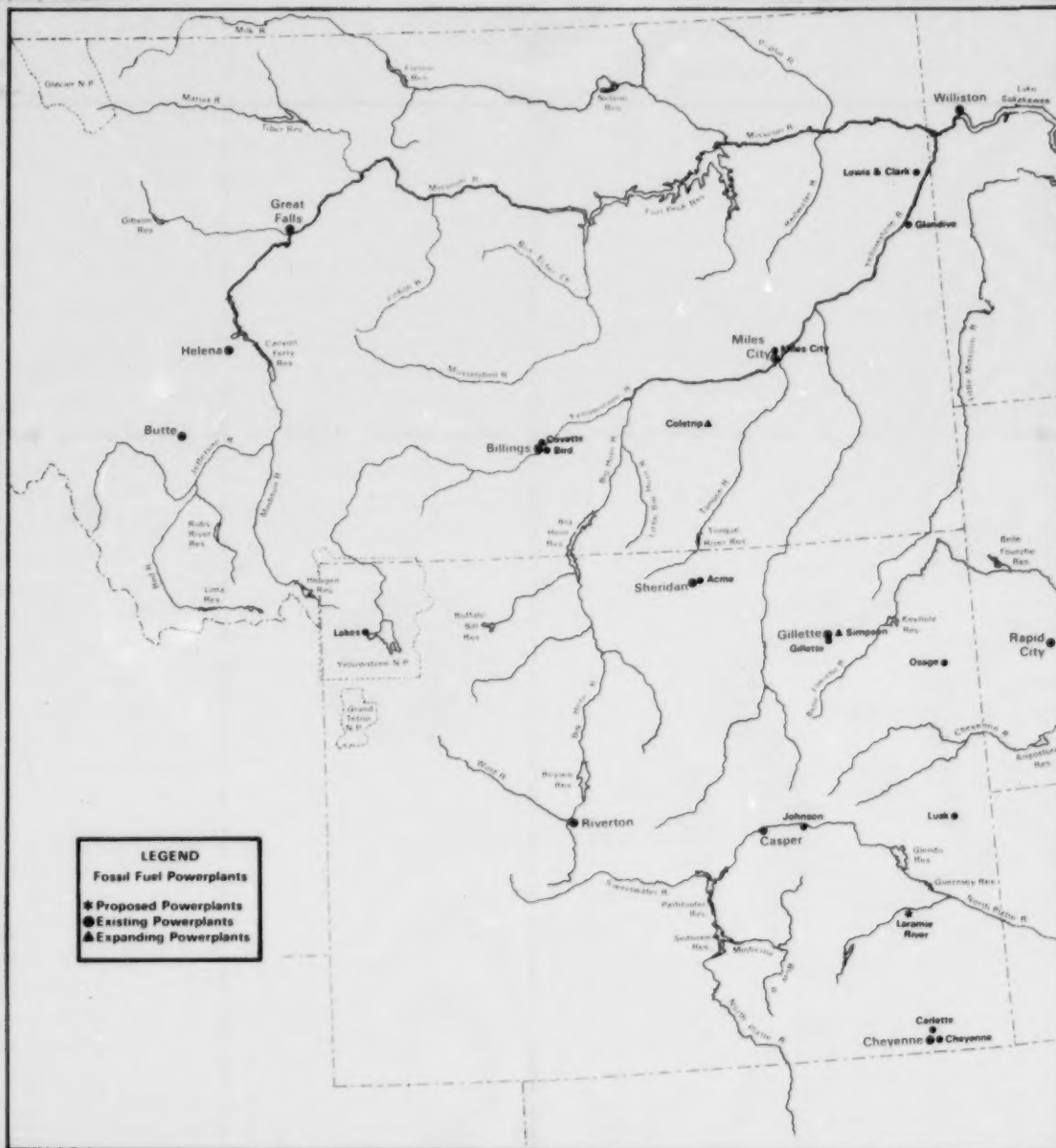


Figure 6. Fossil fuel generating plants in the Yellowstone, Little Missouri, Belle Fourche, and North Platte River systems (Primary source: Federal Power Commission 1977).

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
LAST LINE
OF TEXT

3/8"

18

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

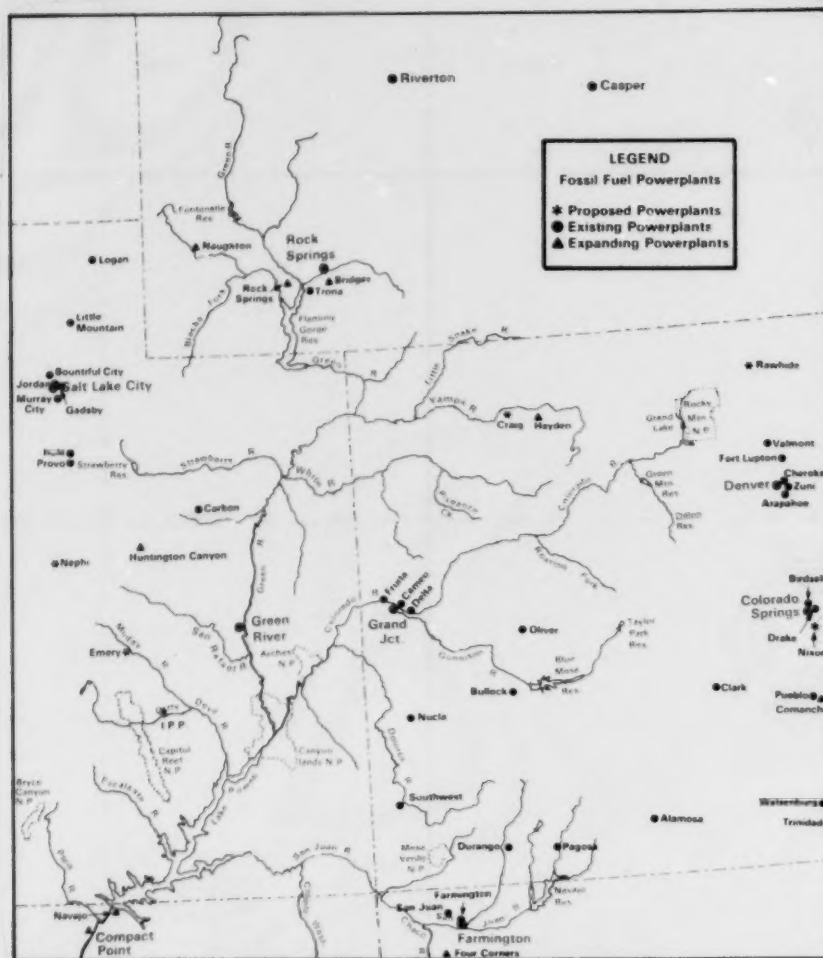


Figure 7. Fossil fuel generating plants in the San Juan, Colorado, and Green River systems (Primary source: Federal Power Commission 1977).

amount and type of water contamination. In the Rocky Mountain States, coal deposits generally contain insignificant quantities of pyrite and are found among alkaline soils (Gluskoter et al. 1977). As a results, the acid mine drainage problems of the East are not common in the area.

Underground mining avoids or reduces many of the problems associated with strip mining, but ground-water contamination may still occur. Pumping of seepage from mining shafts may result in surface discharge. The subsequent washing, refining, storage, and transportation of coal, oil shale, or uranium ores can also introduce contaminants into western waters. The use of coal slurry lines to transport coal provides large quantities of polluted water at the receiving end and presents the possibility for a major pollution event in

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA,
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

the case of a break in the line. Coal slurries require about one cubic meter of water to move one metric ton of coal (Jones et al. 1977), placing additional demands upon an already scarce commodity.

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

OIL SHALE

Rich deposits of oil shale occur in the western energy resource development region. These are primarily associated with the Green River Formation which underlies nearly 65,000 square kilometers (km^2) in Utah, Colorado, and Wyoming (Figure 8). Of this, about 44,000 km^2 are believed to contain commercially exploitable reserves (U.S. Department of Interior 1973). To date, six oil shale tracts have been offered for public lease, but only the Utah and Colorado tracts (Figure 8) have been purchased (Crawford et al. 1977). Activity on several privately owned oil shale reserves is ongoing. To date, all efforts are largely experimental.

In addition to mining and surface retort activities, tests of in situ technology are ongoing. Commercial oil companies have conducted experiments in the Piceance Creek and Uinta Basins (Crawford et al. 1977). In situ fracturing experiments are also being conducted by the government near Rock Springs, Wyoming, and in the Uinta Basin, Utah (Shih et al. 1976).

Oil shale development has two major drawbacks. First, it is a large consumptive user of water ($14 \times 10^6 \text{ m}^3$ per year for a 159,000- m^3 -oil-per-day production plant using the Parahoe retorting process), and second, retort effluent water contains inorganic salts and complex organic compounds including some suspected carcinogens (Conkle et al. 1974). Surface retort processes also increase the volume of extracted shale from 12 to 60 percent. The spent shale is high in sodium, calcium, magnesium, sulfate, and other salts and requires wetting to stabilize it prior to disposal (Hughes et al. 1974). The most likely disposal method will be backfilling and filling of nearby valleys and canyons. The potential for pollution of downslope water resources is very large. Seven elements of particular environmental concern singled out by Dean (1976) in an assessment of the geochemistry of oil shale were cadmium, antimony, arsenic, mercury, selenium, fluorine, and boron. In situ technologies have a very high potential for direct contamination of ground waters. Research has shown that generally the higher the carcinogenicity of the compound (polycyclic aromatic hydrocarbons) the more soluble it is in water and that certain salts enhance this solubility (Institute for Environmental Studies 1975).

The ultimate limit on the size of the oil shale industry will probably be determined by the availability of water. Hughes et al. (1974) estimated available water to be between 2.4 and $4.0 \times 10^6 \text{ m}^3$ per day, enough to support a 0.24 to $0.40 \times 10^6 \text{ m}^3$ per day (1.5 to 2.5×10^6 barrels per day) oil shale industry. Ground-water resources in the Piceance Creek Basin are estimated at between $3,084 \times 10^6 \text{ m}^3$ and $20,840 \times 10^6 \text{ m}^3$. (Institute for Environmental Studies 1975). An amount of water equal to $12,000 \times 10^6 \text{ m}^3$ is sufficient for a $0.16 \times 10^6 \text{ m}^3$ per day industry for about 34 years. However, not all of the ground water in the Piceance Creek Basin is of sufficient quality to be suitable for use.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA,
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

20

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

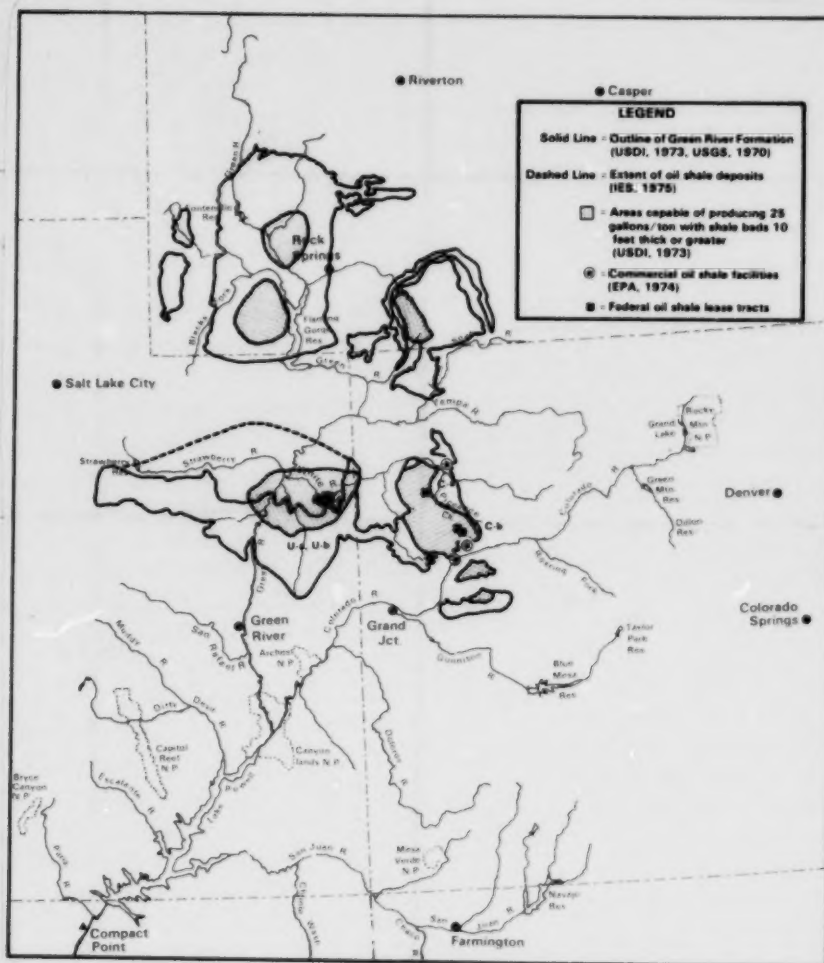


Figure 8. Oil shale reserves in the Western United States (from U.S. Geological Survey 1970; U.S. Department of Interior 1973; U.S. Environmental Protection Agency 1974; and Institute for Environmental Studies 1975).

Spiraling development and production costs, coupled with uncertainties in the national oil policy and in world crude oil prices, have caused interest in development of oil shale to fluctuate. Original plans called for development of surface processing supported by mines. Recent advances in technology now place emphasis on in situ or modified in situ methods (mining and rubbing followed by in situ retorting) (Crawford et al. 1977). Presently, initial development of Federal lease tracts Ca and Cb is occurring rapidly using a mine and underground burn procedure. Development of privately owned tracts is also underway, but large scale development of oil shale reserves is not anticipated prior to the late 1980's.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

GAS AND OIL

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

Gas and oil resources are widespread throughout the western energy resource area but, with some exceptions, exist mainly as relatively small, isolated fields. For example, the eastern Powder River geologic structural basin (Wyoming) alone has over 210 fields producing oil and gas (Everett 1979). Oil production from the west in 1973 was about $56 \times 10^6 \text{ m}^3$ with known reserves estimated at about $400 \times 10^6 \text{ m}^3$ while gas production was about $50 \times 10^9 \text{ m}^3$ with reserves estimated at $590 \times 10^9 \text{ m}^3$ (University of Oklahoma and Radian Corporation 1977). The projected 1985 demand for natural gas is between 300 and $500 \times 10^6 \text{ m}^3$ per year (U.S. Atomic Energy Commission 1972).

In addition, there are widespread areas of potential oil and gas reserves that are presently commercially unexploitable because of the host rocks low permeability (Project Gasbuggy Joint Office of Information 1967). Experiments with hydrofractionation (the fracturing of bedrocks using injection of high-pressure water) were conducted in the area. The U.S. Bureau of Mines estimates that about $8.5 \times 10^9 \text{ m}^3$ of natural gas are potentially recoverable by nuclear stimulation (U.S. Atomic Energy Commission 1972). Project Gasbuggy in northern New Mexico and projects Rio Blanco and Rulison in west-central Colorado detonated nuclear devices in host rocks to stimulate gas flow. These experiments were successful to various degrees and others were planned (U.S. Environmental Protection Agency 1974). Public opposition, changing political policies, and development of other resources (including the Alaska North Slope oil reserves) led to a suspension of such activities. Their eventual resumption is presently a matter of speculation.

Water flooding, a process in which water is used to flush petroleum out of reservoir rocks, is widely practiced in the area (Taylor 1978). Production ground-water wells for this purpose are completed in aquifers that range from shallow, freshwater, alluvial aquifers to deeply buried, highly saline, bedrock aquifers.

The impacts of the development of oil and gas reserves on the environment are well documented. Increased salt loadings are expected and are already a problem in some abandoned fields. Mud pits associated with well-drilling activities (used for mixing mud and circulating water) can break open and discharge mud, oil, and contaminated water into nearby water courses. These also may contribute to local contamination of ground-water supplies. Storage tanks and pipelines have long and continuing histories of minor leaks and catastrophic spills (Figures 9 and 10).

Contamination of ground water through brine disposal ponds, evaporation basins, faulty well casings or completions, or deep-well injection of wastes is a documented problem. In addition, the use of nuclear explosives adds the additional concern of man-induced radiation contamination. These problems can only be controlled by strict enforcement actions and strong incentives for the industry to utilize proper practices and to maintain equipment in good order to reduce leakage and failure.

BEGIN
LAST LINE
OF TEXT

Known oil and gas fields in the region are presently well developed. Little future development is expected except in localized areas. Discovery of

BOTTOM OF
IMAGE AREA,
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE



9-1/8" Figure 9. Old oil pump showing leakage.

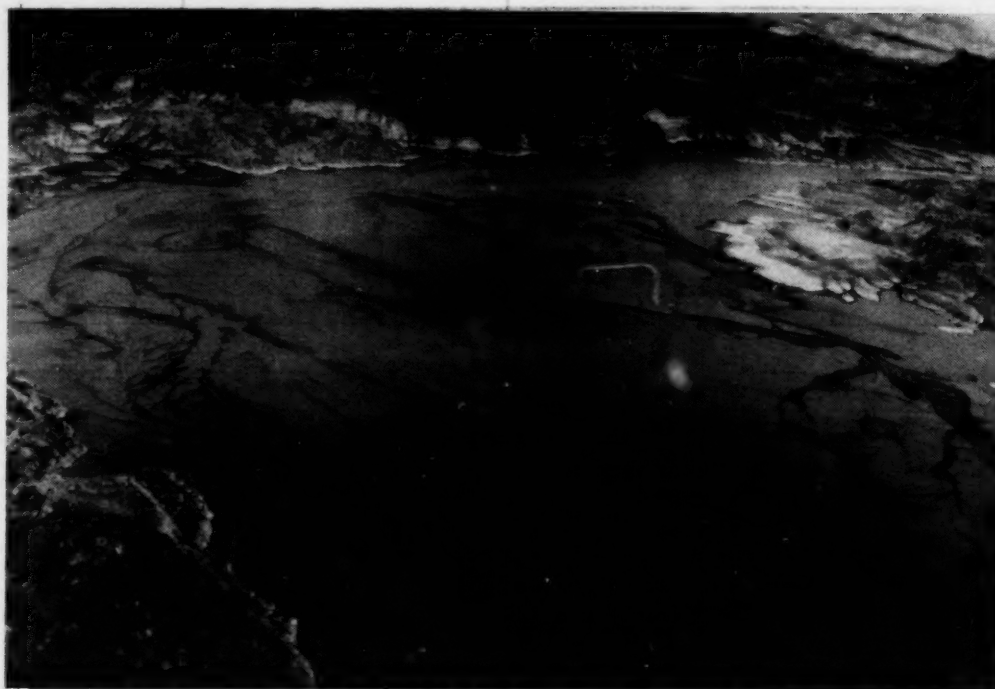


Figure 10. San Juan River 1962 oil spill from ruptured pipeline.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

new, large fields is a possibility but is not considered likely in the area. New, more efficient recovery methods may result in reopening of abandoned fields or areas that are presently uneconomical to develop (National Petroleum Council 1973).

DROPPED
HEAD
BEGIN
SECTIONS
HERE

OTHER ENERGY RESOURCES

In addition to fossil-fuel resources, the study area contains considerable amounts of uranium, geothermal, and hydroelectric resources. The latter are highly developed, and future increases will largely be the result of upgrading present equipment and installing generators at presently unequipped dams (U.S. Bureau of Reclamation 1977b). Some new reservoirs may be constructed, and increased use of pumped storage to supply peaking power is expected.

Uranium deposits in the study area are estimated at 181×10^6 to 272×10^6 kilograms (kg) yellowcake (University of Oklahoma and Radian Corporation 1977). (Yellowcake is processed uranium ore consisting of 85 to 95 percent uranium tri-oxide (U_3O_8) (Reed et al. 1976). The locations of uranium reserves and active mines are indicated in Figure 11.

Impacts from uranium mining are similar to those for coal. Many uranium mines are located in aquifers. Ground-water seepage into mines is often discharged to the adjacent land surface or may be utilized in dust control or mill process waters (Water Resources Work Group 1971).

Large quantities of solid wastes must be disposed of at milling sites; about 98 percent of all processed ore is discharged as tailings (Reed et al. 1976). Tailings are historically discharged directly into streams or piled on flood plains near streams. The tailings piles are highly susceptible to erosion, and even minimal contact with water will produce an effluent in excess of permissible limits. In addition to radioactive compounds that may leach or erode from tailing piles, milling wastes are frequently high in total dissolved solids and are either strongly alkaline or acidic (Water Resources Work Group 1971). Water seeping from tailing piles may contain trace elements, nitrates, sulfates, or organic compounds that will degrade or pollute ground or surface waters (Reed et al. 1976). Other potential sources of exposure from tailings include inhalation of windblown particulates or gases diffusing from the piles and external whole-body gamma exposure.

Tailings are presently discharged into impoundments primarily to retain the solid wastes but also to settle and segregate the liquid wastes. Some liquid wastes have been disposed of by deep-well injection. If properly conducted, this disposal method is acceptable; however, contamination of aquifers from injected wastes appears to have occurred in New Mexico (Reed et al. 1976). Seepage or spills from tailing ponds may contaminate shallow aquifers or surface waters. The ponds generally support little aquatic life because of their high pH and the presence of toxic substances. The effects on animals such as waterfowl that may inadvertently use the ponds are not known (Reed et al. 1976).

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
LAST LINE
OF TEXT

3/8"

24

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

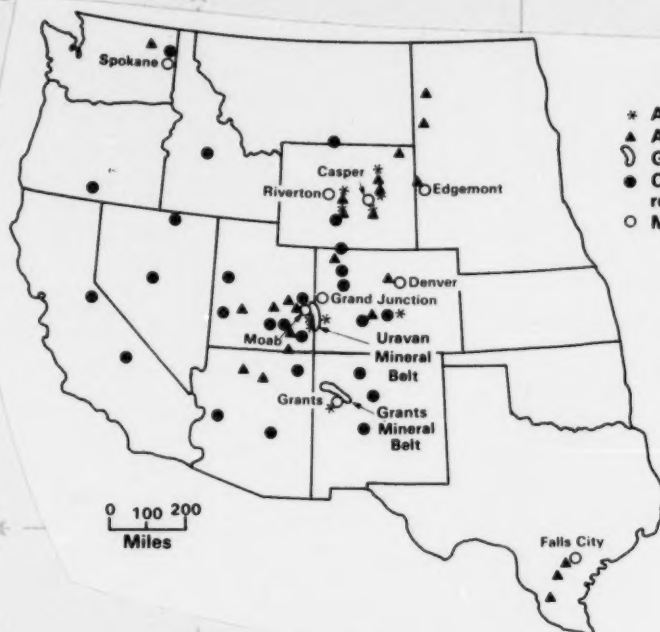
BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE



- * Active Uranium Mills
- ▲ Areas with production and \$35.00 reserves
- Greater than 500 tons U_3O_8 (Names Shown)
- Other areas with production and \$35.00 reserves greater than 10 tons U_3O_8
- Major Cities

Figure 11. Uranium reserve regions, Western United States
(from Larson 1978).

Recently, in situ extraction of uranium has become more common, particularly in Wyoming and New Mexico. In situ leach mining consists of injecting a suitable leach solution into the ore zones below the water table to oxidize, complex, and mobilize the uranium. The resultant solution is recovered by pumping it to the surface through production wells for further processing. The leach solution is usually a diluted concentration of ammonium carbonate-bicarbonate or sulfuric acid; the oxidizing agent is usually hydrogen peroxide or oxygen. Once the uranium minerals are solubilized and complexed, they follow the solution flow through the ore zone to a production well. The uranium in the leach solution is recovered by ion exchange techniques. The processed leach solution is regenerated and recycled to the well field. When the absorption resin is sufficiently loaded, the uranium is stripped from the resin using a suitable chemical, then precipitated from the solution, thickened, filtered, dried, and packaged for shipment (Larson 1978).

Potential for pollution is present throughout the process. Of special concern is ~~contamination of ground water, both by escape of the injected solution and from cross-contamination to different strata via the injection and production wells.~~

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

Reed et al. (1976) provides a very good summary of uranium mining activities in the United States. They list tailing ponds and the resultant ponded materials as the primary environmental concern. Both have caused environmental problems in the past. Deep-well injection disposal and in situ leach mining activities need to be closely monitored in order to minimize any problems.

Geothermal resources have not been accurately characterized, but most estimates range from 5,000 to 6,000 megawatts (MW) electrical output capacity. Activity in the region is primarily exploratory with some experimental development occurring at a few locations. Development of geothermal resources is expected to produce saline brines rich in trace elements, large amounts of waste heat and noise, and, in some locales, large amounts of sulfur-rich water and fumes. Most areas will require large amounts of water both to produce steam and to provide for cooling. In the near future, development of these resources in the study area is expected to be limited to a few experimental sites (University of Oklahoma and Radian Corporation 1977).

There are also limited amounts of tar sands, gilsonite, and other fossil fuel reserves that may be exploited in the region. Gilsonite is currently mined for purposes other than use as a fuel. No exploitation of tar sands is presently occurring in the United States (Corsentino 1976).

The study area receives a large amount of solar radiation, usually over 400 gram calories per cm² per year, and is cloud-free much of the time (U.S. Geological Survey 1970). The large amount of unused land in the region makes it a prime candidate for large-scale solar radiation facilities in the long-term future. In the near term it is doubtful that any significant development of solar energy facilities will occur.

TRANSPORTATION

Facilitation of energy resource development requires sufficient transportation systems to economically expedite fueling of powerplants and distribution of electricity. Coal deposits are usually distant from adequate supplies of water necessary to cool electrical generating powerplants, and the ultimate consumers of this electrical energy may be equally distant from its source of generation. Transportation systems that may have an environmental impact include roads, railroads, gas and oil pipelines, coal slurry pipelines, and electrical transmission lines.

The University of Oklahoma and Radian Corporation (1977) study points out that railroad coverage of the major coal deposit areas of the Rocky Mountain and Northern Great Plains regions is weak. For instance, in the Four Corners region an average of 240 km of spur-track line is needed to connect any new mine to a main-truck rail line. As coal deposits become actively mined and new power generation facilities come on line, the demand to expand rail service will be severe. Saturation of existing rail lines to handle coal transport will occur within one decade. If 25 million tons of raw coal per year were to be transported on one set of double track to supply powerplants

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

LAST LINE
OF TEXT

3/8"

26

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

in the region and outside markets, 29,000 km of additional track, at a cost of \$5.5 billion, would be needed by the year 2000.

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

Only one coal slurry pipeline, that connecting the Black Mesa Mine and the Mohave Powerplant in Arizona, is in operation in the United States at this time (Jones et al. 1977). Several pipelines have been proposed to transport coal both within and outside of the western energy resource region. The Office of Technology Assessment (1978) reviewed coal slurry pipeline technology, feasibility, and impacts. They concluded that pipelines can transport coal more economically than other modes when high annual volumes of coal must be shipped over long distances from large, closely spaced mines, when terrain characteristics are favorable to pipeline construction, when adequate low-cost water and electric power for pumping are available, and when some economic considerations are satisfied. They found that sufficient water was generally physically available for planned pipelines but was not necessarily legally available. Competition for water with other future uses will also occur. Alternatives such as mine-mouth power generation, coal gasification, and coal liquefaction all require larger amounts of water for a given amount of coal than pipelines. Disposal of excess water at the receiving end of the pipeline will be necessary and will require treatment prior to use or discharge.

Gas and oil pipeline systems are currently adequate in most areas of the region. It is anticipated that existing oil and natural gas pipelines will transport synthetic hydrocarbon products in the near future as coal gasification and liquefaction operations begin and natural gas and crude oil supplies become exhausted. It will be necessary to construct an additional 93 billion m³ pipeline capacity requiring an estimated 215 km² of land for right-of-way to meet projected supply deliveries by the year 2000 (University of Oklahoma and Radian Corporation 1977). Spills from such pipelines have occurred in the past (Figure 10) and will undoubtedly occur in the future.

As each new mine-mouth electrical generating powerplant comes on line, new transmission lines are required to connect it with major distribution networks. Substantial links between the Four Corners power facilities and the Phoenix, Tucson, and Los Angeles markets exist. Although Federal and private utility distribution networks exist throughout the West, interconnections of power between different river basins and between distant regions are poorly developed. Interconnection networks offer reliability of future electricity supplies and effectively handle seasonal surpluses. Interconnection capacities are highly desirable from a conservation standpoint since power generation redundancies can often be eliminated. However, mechanical, administrative, and planning contingencies currently make large-scale implementation of the system complex and economically impractical. Expansion of power transmission systems to meet demands by the year 2000 will require 21,000 km of new line of a 2,200 MW capacity. Impacts from this expansion will be minimized by replacing older 230 kilovolt (kV) capacity grids with 345 kV, 500 kV, and higher capacity lines installed in existing transmission corridors (U.S. Bureau of Reclamation 1977b). Concern over the effects of high frequency radiation from power transmission lines is growing. Public reaction has already slowed construction or forced relocation of power lines in several areas.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA,
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

CONVERSION AND REFINING

DROPPED
HEAD
BEGIN
SECTIONS
HERE

Conversion and refining of uranium ores, coal, and oil shale will require large amounts of water, both for processing and for cooling. Waste disposal and cooling ponds have potential for both surface- and ground-water pollution. In situ conversion will introduce organic contaminants to ground-water systems. Soviet studies on large-scale underground coal gasification projects have found ground-water contamination that persisted up to five years after production had ceased (Humenick and Mattox 1978).

POWER GENERATION

Electric power generation may cause pollution in several ways. Waste heat from combustion must be dissipated into the environment. Coal- or oil-fired plants produce stack emissions that may cause deposition of volatile trace elements over wide areas (Figure 12). Combustion of coal acts to concentrate nonvolatile residues in the ash and slag wastes (Radian Corporation 1975). The removal of sulfur and particulates from stack gases produces a sludge rich in sulfates and elemental forms (Wewerka et al. 1976). Disposition of ashes or sludges may lead to subsequent leaching of contaminants into nearby waters. Concentration of chemicals in cooling system blowdown waters through evaporative processes, introduction of biocides or scale removers, etc. produce low-quality water. Discharge from plant wastes, cooling ponds, or coal or oil stockpiles into waterways may occur with varying degrees of impact (University of Oklahoma and Radian Corporation 1977).

WASTE DISPOSAL

Coal gasification and liquefaction, oil shale processing, steam electric generation, uranium extraction, and other energy resource development activities all produce process streams and wastes rich in pollutants. Great care will have to be taken to ensure that final disposition of these effluents does not introduce contaminants, many of which may be carcinogenic, mutagenic, or teratogenic, into the environment (University of Oklahoma and Radian Corporation 1977). Both steady discharge from plant processes and accidental releases are of concern. One study (University of Oklahoma and Radian Corporation 1977) notes:

"Holding pond berm designs must be site specific and failures are common in areas where previous design experience is not available. If accumulations of wet-solids containing heavy metals, trace elements, and complex aromatic hydrocarbons are released accidentally, they could provide acute effects in local surface waters. The quantities involved are quite large . . . 12.6-101.6 million tons of solids will accumulate over 25 years from just one facility at one site."

BEGIN
LAST LINE
OF TEXT

Another study of nine surface-mine sedimentation ponds by Kathuria et al. (1976) in eastern mining areas found that poor construction and inadequate maintenance were major problems. During a rain the ponds had much lower removal efficiencies than predicted. On the basis of these two reports, the

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

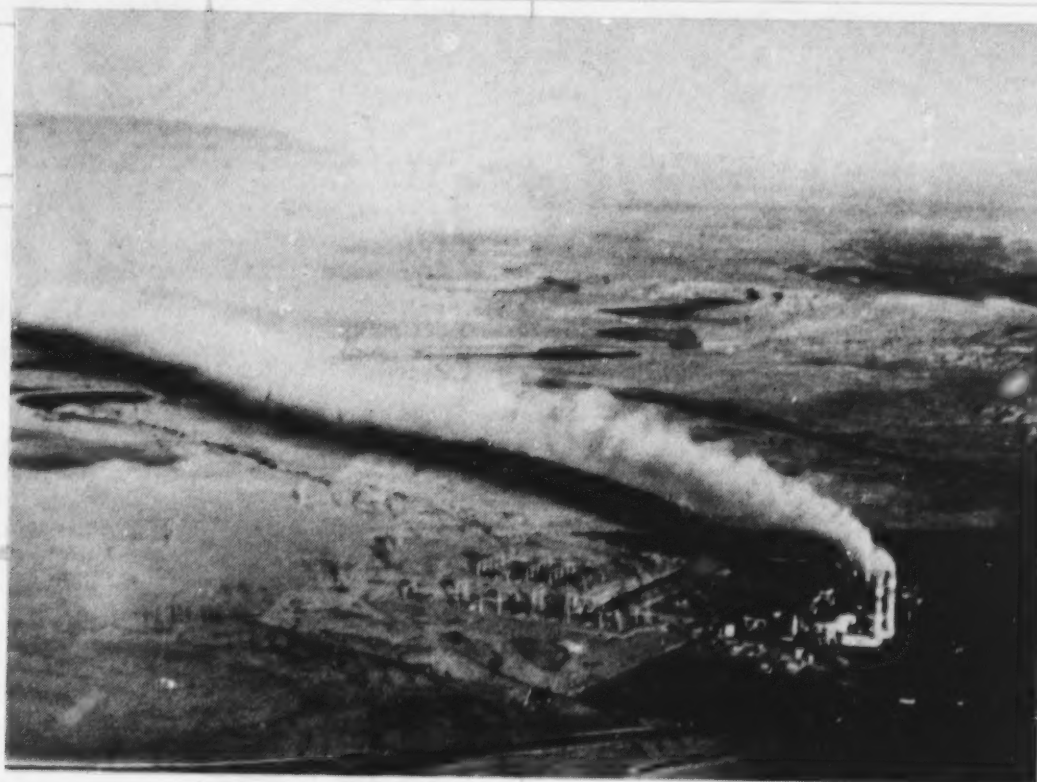


Figure 12. Stack plume from coal-fired powerplant emission.

expectation of holding pond failure and spills to the environment must be quite high. Figure 13 shows just such a spill, a uranium tailing pond failure that resulted in discharge to an intermittent stream.

OTHER

In addition to the direct impact of western energy resource development through extraction, transportation, processing, and use of these resources, secondary impacts will be common. Impacts will result from an increased population, development of metallic and nonmetallic resources to provide the necessary products for construction and development (concrete, steel, etc.), production of by-products, supportive industries (implied by an increased population), etc. As an example of secondary impacts, Figure 14 shows a water supply truck filling from a New Mexico stream (A) while leaking crankcase oil into the water (B).

BEGIN
LAST LINE
OF TEXT

Albers et al. (1976) reviewed the nonfuel mineral demands for the United States energy industry and arrived at the values presented in Table 4. Those materials likely to be mined in the western energy resource region are indicated.

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

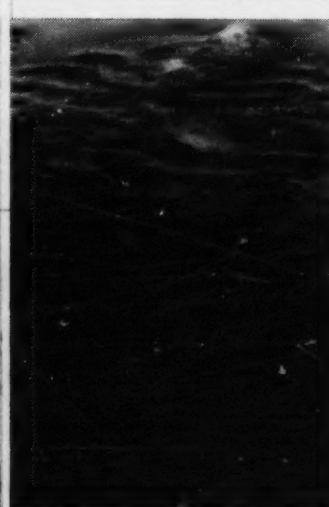
CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD:
BEGIN
SECTIONS
HERE



9-1/8" Figure 13. Uranium tailing pond failure.



BEGIN
LAST LINE
OF TEXT

Figure 14. (A) Water supply truck (B) Oil from crankcase leak.

BOTTOM OF
IMAGE AREA:
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

TABLE 4. MINIMUM ESTIMATES OF NONFUEL MINERAL AND MATERIAL REQUIREMENTS
FOR ENERGY PRODUCTION IN THE UNITED STATES, 1975-90
(Albers et al. 1976)

Commodity	Total Demand (metric tons)	Largest Energy Source Users
Aluminum	18,400,000	Transmission; coal*; solar
Antimony**	1,070	Coal
Asbestos	147,000	Oil and gas refining; geothermal; nuclear
Barite	29,200,000	Oil, gas, and oil shale development
Bentonite**	12,700,000	Oil, gas, and oil shale development
Boron	41	Coal; uranium mining and processing
Cadmium**	130	Coal; uranium mining and processing
Chromium**	264,000	Nuclear; oil, gas, and oil shale development
Cobalt	1,760	Fossil fuel powerplants
Concrete**	348,000,000	Hydroelectric; nearly all
Copper	4,690,000	Transmission; powerplants
Fluorite**	1,980,000	Transmission; oil, gas, and oil shale and development; solar
Indium	145	Nuclear powerplants
Iron	213,000,000	All
Lead**	25,300	Nuclear powerplants, uranium and coal mining
Magnesium	1,310,000	All (required for steel production)
Manganese	2,080,000	Oil, gas, and oil shale development
Mica	5,410	Hydroelectric
Molybdenum**	78,800	Nuclear powerplants
Nickel	264,000	Nuclear powerplants
Niobium	933	Oil, gas, and oil shale development
Silicon	815,000	Oil, gas, and oil shale development; solar; transmission
Silver	1,120	Nuclear powerplants
Tin	1,540	Nuclear powerplants
Titanium**	7,020	Geothermal powerplants
Tungsten**	40,100	Oil, gas, and oil shale development
Vanadium	3,810	Oil and gas refineries
Zinc**	3,260	Uranium mining
Zirconium	27,500	Nuclear powerplants

*Includes mining and transport

**Ore deposits exist in western energy resource region

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

WATER AVAILABILITY

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

Energy resource development activities will require large and continuous amounts of water. This need, coupled with increasing demand and competition from other water users, should ultimately result in increased water management. Construction of new dams, aqueducts, pipelines, wells, and other control structures will further disrupt naturally occurring hydrologic cycles. Evaporation from reservoir surfaces is second only to agriculture in water consumption. The impact of a reservoir on water quality may be either positive or negative; a reservoir may act as a settling basin and reduce both suspended and dissolved solids loads or it may raise dissolved concentrations through evaporation. Reservoirs, once constructed, often become popular recreation areas and demands for high-quality water become even more pronounced.

Surface water presently supplies nearly all of the water needs of the area (Price and Arnow 1974; Taylor 1978). Although the amount of recoverable ground water in the upper 30 meters of saturated rocks in the Upper Colorado River Basin alone is estimated at $142 \times 10^9 \text{ m}^3$, ground water supplies less than 2 percent of the total water withdrawn and consumed (Price and Arnow 1974). Future water requirements in the western energy development region will necessitate utilization of ground-water resources. Appraisals of these resources, development scenarios, and potential environmental problems are discussed by Price and Arnow (1974) and Taylor (1978).

In the western energy resource region water availability may ultimately limit energy resource, agricultural, and urban development. Water shortages place even greater importance on surface-water quality; throughout the area recreational use of natural resources is high and high-quality water resources are particularly treasured. Energy resource development has potential for impacting the quality of both surface- and ground-water resources. This impact may be a direct result of resource development activities or it may be the result of secondary impacts of population growth resulting from development-related employment opportunities.

ELEMENTAL POLLUTANTS

A relatively large amount of data has been collected on the elemental composition of coal and its process streams and wastes. Less data are available for coal conversion streams and releases during in situ processing. A large amount of data is also available for oil shale and spent-shale elemental compositions. Some data are available for most energy development processes, including in situ oil shale processes.

The elemental composition of representative western coals is presented in Table 5. Arsenic, boron, bromine, lithium, molybdenum, niobium, sulfur, and selenium are concentrated in coals above average crustal-rock levels. Gluskoter et al. (1977), evaluating U.S. coals, found only arsenic, boron, chlorine, and selenium in concentrations significantly above those in the Earth's crust, but boron was only concentrated in Illinois coals, not western

BEGIN
LAST LINE
OF TEXT

3/8"

32

EPA-257 (Cin.)
(4-76)

PAGE NUMBER

T-5
BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 5. ELEMENTAL COMPOSITION OF COAL (mg/kg) FROM A NUMBER OF COAL FIELDS
THROUGHOUT THE WESTERN ENERGY DEVELOPMENT AREAS

DROPPED
HEAD
BEGIN
SECTIONS
HERE

Element	Navajo Mine Coals							Calculated Ground Deposition
	Navajo Mine Coal Average from 7 Seams	Navajo Mine Comp	Burnham Mine Coal	Bottom Ash	Fly Ash	Stack Particulates	Navajo Mine Overburden (Average)	
Antimony	0.42	0.13	0.3-1.2	0.5-0.8	0.4	0.9	0.46	
Arsenic	1.20	1.1	0.1-3.0	0.8-1.1	11	30	2.0	0.39-0.5
Barium	140.00	1		0.5	1.0	0.5	717	4.5-39.3
Beryllium	3.40	1.5	2-3.0	5	6	5	<1	
Bismuth	<0.10	1	0-0.2	10	10	10	<30	
Boron	75.00	80	60.0-150.0	200	700	300	41	
Bromine	1.70		100					
Cadmium	0.66	1	0.2-0.4	0.7-3.2	1.6	4	<10	
Cerium	15.00		150-200					
Cesium	0.32							
Chromium	4.60	4		20	60	20	16	
Cobalt	1.60	2		10	10	10	23	
Copper	44.00	14		53-57	80	65	40	
Dysprosium	0.68							0.1-1.1
Erbium	0.24							
Europium	0.46							
Fluorine	210.00	44	100	7-17	100	900	417	
Gadolinium	<0.33							53-455
Gallium	12.00	8	0.5-8.0	30	400	40	27	
Germanium	0.90	<6	0.1-0.5	30	30	30	<10	
Gold	<0.10							
Hafnium	0.44							
Holmium	<0.11							
Iodine	0.45							
Iridium	<0.10							
Lanthanum	10.00							
Lead	5.50	6.3	1.4-4.0	23-26	62	50	36	
Lithium	85.00	50		200	200	200	83	0.04-0.45
Lutecium	<0.35							
Manganese	130.00	40	500	200	300	200	455	
Mercury	0.01	0.08	0.2-0.3	0.3-0.6	0.13	0.30	0.055	
Molybdenum	4.90	0.8		3	10	3	<10	0.1-0.6
Neodymium	13.00							
Nickel	2.90	4	3.0-30.0	20	30	20	19	
Niobium	5.60	<2		10	10	10	<20	
Osmium	<0.10							
Palladium	<0.10							
Platinum	<0.10							
Praseodymium	3.40							
Rhenium	<0.10							
Rhodium	<0.10							
Rubidium	4.60							
Ruthenium	<0.10							
Samarium	0.75							
Scandium	4.00						10	
Selenium	0.74	2.7	0.1-0.2	0.2-1.5	6.6	27	<0.5	
Silver	0.03	<0.2		1	1	1	<5	
Strontium	53.00	40		300	500	300	133	
Tantalum	0.39							0.35-1.96
Tellurium	0.20							
Terbium	<0.11							
Thallium	<0.15							
Thorium	3.60							
Thulium	<0.11							
Tin	1.40	<0.6		3	3	3	<5	
Tungsten	6.90							
Uranium	0.66							
Vandium	21.00	20	300-500	50-70	200	60	35	
Ytterbium	<1.10							
Yttrium	13.0							
Zinc	12.00	6	1.1-27.0	10	100	10	38	0.07-0.68
Zirconium	140.00	40		200	300	300	142	

BEGIN
LAST LINE
OF TEXT

3/8"

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

coals. Western coals were found to have higher concentrations of barium, calcium, sodium, phosphorus, and strontium than eastern coals.

DROPPED
HEAD
BEGIN
SECTIONS
HERE

During coal mining, handling, storage, and use, trace elements may enter the environment through volatilization or solution or become concentrated in coal wastes. Wewerka et al. (1976) found that effluents from western coals had relatively low total salt contents, high pH values, and modest concentrations of metallic elements when compared to eastern acid-spoil drainages. Wachter and Blackwood (1978), using coals from Montana, New Mexico, and Wyoming, determined the average effluent concentrations from a simulated rainfall (Table 6). They found that aged coals not exposed to recent rainfalls had higher runoff concentrations than new coals or coals recently exposed to rainfall. These concentrations, diluted as the runoff flowed across open areas to the nearest waterway, were calculated as ranging from one to seven orders of magnitude lower than established water-quality criteria.

Van Meter and Erickson (1976) estimate that a typical 7 million m³ per day gasification plant will produce about 400,000 metric tons of slag or ash per year. They note that "virtually all the trace elements content of the coal will remain in this solid waste and will probably be more soluble. . . ." Elutant from wastes contained large amounts of soluble caustics, primarily CaO and Ca(OH)₂. Elutant pHs ranged from 12.5 to 11.2. Metals other than alkalies and alkaline earths were extremely low; only zinc and manganese were detected by atomic absorbtion methods.

Klein et al. (1975) traced the pathways of 37 trace elements through a coal-fired powerplant in Tennessee. The coals used were from Illinois and Kentucky, but it is felt that element flows would be similar to those of western coals. They found that aluminum, barium, calcium, cerium, cobalt, europium, iron, hafnium, potassium, lanthanum, magnesium, manganese, rubidium, scandium, silicon, samarium, strontium, tantalum, thorium, and titanium were readily incorporated into the slag and were partitioned evenly between the inlet fly ash and the slag. Arsenic, cadmium, copper, gallium, lead, antimony, selenium, and zinc were concentrated in the fly ash, while mercury, chlorine and bromine remained in the gaseous state and escaped into the atmosphere.

Ray and Parker (1977) characterized fly ash composition. They found that it varied widely but was 95 to 99 percent silicon, aluminum, iron, and calcium while magnesium, titanium, sodium, potassium, sulfur, and phosphorus comprised from 0.5 to 3.5 percent. The remainder consisted of up to 50 trace elements. Bromine, chlorine, fluorine, mercury, sulfur, and selenium were generally discharged to the atmosphere during coal combustion. Arsenic, cadmium, copper, gallium, molybdenum, lead, antimony, sulfur, zinc, and, to a lesser degree, selenium, chromium, and nickel were preferentially concentrated in the fly ash. Elemental composition of ashes from U.S. coals are presented in Table 7.

BEGIN
LAST LINE
OF TEXT

Common disposal of fly ash is by ponding the scrubber or precipitor effluent on site and later mining the material and depositing it as fill. Theis et al. (1976) investigated trace-element migration into ground water

T-7
BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 6. AVERAGE EFFLUENT CONCENTRATIONS FROM WESTERN COAL STOCKPILES (mg/l)
(from Wachter and Blackwood 1978)

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

Element in Effluent	Montana Coal	Wyoming Coal	New Mexico Coal
Antimony (Sb)	ND	14.0	6.5
Arsenic (As)	1.8	5.6	4.1
Beryllium (Be)	ND	ND	ND
Cadmium (Cd)	ND	0.005	ND
Chromium (Cr)	ND	0.04	ND
Copper (Cu)	ND	ND	0.02
Iron (Fe)	1.5	8.2	5.5
Lead (Pb)	0.05	0.07	0.05
Manganese (Mn)	0.14	0.4	0.04
Mercury (Hg)	0.003	0.005	0.002
Nickel (Ni)	0.02	0.05	0.03
Selenium (Se)	ND	15.0	21.5
Silver (Ag)	ND	ND	ND
Thorium (Th)	ND	ND	ND
Zinc (Zn)	0.17	0.15	0.04

ND - Not detected

around a powerplant utilizing Illinois coal. The plant produced between 310 and 365 metric tons of ash per day. They found concentrations of trace elements to be quite low [none exceeded 4 parts per million (ppm)] in ground water near the site but to vary in response to ash loading rates and pond handling procedures.

Chu et al. (1976) found that alkaline fly ash did not release cadmium, iron, mercury, manganese, or lead into alkaline or neutral waters but arsenic, boron, barium, chromium, copper, nickel, selenium, and zinc did solubilize in alkaline sluice water. Barium, boron, chromium, nickel, and selenium concentrations exceeded water-quality criteria. Libicki (1978) investigated changes in ground-water composition over a 2½-year period from an unlined coal-waste disposal pit located in the roof of an aquifer layer in Poland. He found the following increases in ground-water concentrations compared to unaffected aquifer samples: total dissolved solids, 10 times; chlorine, 40 times; sulfate, 10 times; sodium, 100 times; calcium, 6 times; magnesium, 2 times; ammonia, 4 times; phosphate, 8 times; cadmium, 3 times; strontium, 5 times; copper, 6 times; molybdenum, 15 times; boron, 25 times; cyanide, 10 times; and phenols, 2 times.

Pellizzari (1978) analyzed process streams from in situ oil shale and coal gasification experiments and from low-Btu gasification processing of Rosebud coal. The results are summarized in Table 8. Cushman et al. (1977) listed 35 elements for potential release into the environment from coal conversion

BEGIN
LAST LINE
OF TEXT

3/8"

35

PAGE NUMBER

EPA-287 (Cir.)
(4-76)

Tab 8
BOTTOM OF
IMAGE AREA,
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

TOP OF
IMAGE
AREA

TABLE 7. ELEMENTAL COMPOSITION OF ASHES FROM U.S. COALS

Element	Concentration (ppm or mg/kg)					Concentration Factor*
	Mewerka (1976)	Theis et al. (1976)	Chu et al. (1976)	Melancon, 1979a Bottom Ash	Fly Ash	
Aluminum (Al)	53,000-212,000					7.3
Antimony (Sb)	<40-230					110-0
Arsenic (As)	21-570	1,200	55-170	0.8-1.1	11	98.9
Barium (Ba)	100-13,900			0.5	1.0	11.5
Beryllium (Be)	0-1,100			5	6	
Bismuth (Bi)	1-900			10	10	
Boron (B)	30-6,500		400-1,800	200	700	
Cadmium (Cd)		19	<2-6	0.7-3.2	1.6	108.5
Calcium (Ca)	5,800-14,000					7.4
Cerium (Ce)						14.6
Cesium (Cs)						24.5
Chromium (Cr)	<1-1,800	320	90-140	20	60	50.0
Cobalt (Co)	0-600			10	10	22.4
Copper (Cu)	10	350	78-170	53-57	80	16.9**
Europium (Eu)						13.0
Gallium (Ga)	0-540			30	400	18.0**
Germanium (Ge)	0-1,500			30	30	
Hafnium (Hf)						12.5
Iron (Fe)	20,900-244,000					13.8
Lanthanum (La)	0-820					11.1
Lead (Pb)	10-1,420	1,120	75-100	23-26	62	132.7
Lithium (Li)	<20-3,100			200	200	
Magnesium (Mg)	0-24,000					8.8
Manganese (Mn)	30-1,800	600	220-410	200	300	12.7
Mercury (Hg)	<70-259	24	0.1-0.4	0.3-0.6	0.13	0.4**
Molybdenum (Mo)	0-2,900			10	3	
Nickel (Ni)	0-1,200	600	100	20	30	12.9
Phosphorus (P)	<440-3,360					
Potassium (K)	6,600-13,200					15.6
Rubidium (Rb)	<91-1,100					12.3
Scandium (Sc)	2-155					16.4
Selenium (Se)		88	6-8	0.2-1.5	6.6	40.0
Silicon (Si)	93,000-280,000					8.5**
Silver (Ag)	<1-84					
Sodium (Na)	7,100-27,200					16.2
Strontium (Sr)	90-9,600			300	500	10.9
Tantalum (Ta)						16.4
Tin (Sn)	0-4,250			3	3	
Titanium (Ti)	1,000-26,000					19.8
Tungsten (W)	<10-182					
Uranium (U)						13.8**
Vanadium (V)	6-3,800			50-70	200	41.4
Ytterbium (Yb)	<2-23					
Yttrium (Y)	0.620					
Zinc (Zn)	0-16,000	3,300	280-540	10	100	128.3
Zirconium (Zr)	100-1,450			200	300	

*Outlet Fly Ash/Coal

**Based on inlet fly ash concentration

effluents but gave no quantitative values. Attari et al. (1976) found that volatile trace elements (bismuth, cadmium, chlorine, fluorine, mercury, lead, antimony, and selenium) were removed from Montana lignites during HYGAS gasification and appeared in the quench water system.

Hughes et al. (1974) state that the major source of water pollution from the oil shale industry will be from surface disposal of processed oil shale. In particular, sodium, calcium, magnesium, and sulfate ions would be contained in runoff water from spent-shale residues. In addition, they note that in many areas aquifers exist above high-quality shale deposits. Caving, resulting from mining operations, could destroy the integrity of the aquifer

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
LAST LINE
OF TEXT

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 8. MAXIMUM CONCENTRATION (ppm) OF ELEMENTS IN VARIOUS WATER SAMPLES
(from Pellizzari 1978)

DROPPED
HEAD
BEGIN
SECTIONS
HERE

Element	In Situ Oil Shale Process Water	Low Btu Gas- ification of Rosebud Coal Process Water	Pre- In Situ Gasification Well Water	In Situ Gasification Process Product Waters	Post- In Situ Gasification Well Water
Aluminum (Al)	0.5	1.2	0.7	7.5	2
Antimony (Sb)	0.24	.06	0.003	0.01	0.005
Arsenic (As)	2	2.5	0.01	0.05	0.025
Barium (Ba)	0.5	0.07	0.2	0.25	4.0
Beryllium (Be)	<0.001	<0.04	<0.004	<0.008	<0.01
Bismuth (Bi)	<0.001	<0.04	<0.004	0.006	<0.012
Boron (B)	1.5	2	0.02	0.4	0.6
Bromine (Br)	0.3	.04	0.25	0.03	0.15
Cadmium (Cd)	<0.001	<0.04	.009	0.025	<0.01
Calcium (Ca)	2 (MC)*	4.2 (MC)	(MC)	24 (MC)	(MC)
Cerium (Ce)	0.002	<0.04	<0.004	0.003	0.008
Cesium (Cs)	.01	<0.04	0.002	0.05	0.009
Chlorine (Cl)	9.178 (MC)	1.5	4	0.75 (MC)	6 (MC)
Chromium (Cr)	.005	0.47	0.04	0.45	0.06
Cobalt (Co)	0.01	0.015	0.008	0.005	0.02
Copper (Cu)	.6	0.6	0.19	0.75	0.5
Dysprosium (Dy)	0.045	<0.04	<0.004	<0.008	<0.01
Erbium (Er)	<0.001	<0.4	<0.004	<0.008	<0.01
Europium (Eu)	0.001	<0.4	<0.004	<0.008	0.02
Fluorine (F)	8 (MC)	0.6	≈2	≈1.4 (MC)	≈5 (MC)
Gadolinium (Gd)	0.001	<0.04	<0.004	<0.008	<0.01
Gallium (Ga)	0.015	0.06	0.005	0.1	0.05
Germanium (Ge)	0.015	0.04	0.005	0.14	0.015
Gold (Au)	<0.001	<0.004	<0.004	<0.008	<0.009
Hafnium (Hf)	<0.001	<0.04	<0.004	<0.008	<0.01
Holmium (Ho)	<0.001	<0.04	<0.004	<0.008	<0.01
Indium (In)	Trace	Trace	Trace	Trace	Trace
Iodine (I)	0.02	<0.04	.003	<0.003	0.02
Iridium (Ir)	<0.001	<0.04	<0.004	<0.008	<0.01
Iron (Fe)	5.5	2.5 (MC)	0.6 (MC)	7 (MC)	8
Lanthanum (La)	0.001	< .04	<0.004	0.003	<0.002
Lead (Pb)	0.06	0.25	0.02	0.55	0.12
Lithium (Li)	1.2	0.125	0.5	0.01	3.2
Lutetium (Lu)	<0.001	<0.04	<0.004	<0.008	<0.01
Magnesium (Mg)	4 (MC)	7 (MC)	0.009	9	6 (MC)

(continued)

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 8. (Continued)

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

Element	In Situ Oil Shale Process Water	Low Btu Gas- ification of Rosebud Coal Process Water	Pre- In Situ Gasification Well Water	In Situ Gasification Process Product Waters	Post- In Situ Gasification Well Water
Manganese (Mn)	0.06	<0.4	0.5	0.2	0.95 (MC)
Mercury (Hg)	0.001	0.005	<0.009	0.066	<0.23
Molybdenum (Mo)	0.6	<0.04	0.3	0.5	0.07
Neodymium (Nd)	0.003	<0.04	<0.004	0.01	<0.01
Nickel (Ni)	0.08	1.85	0.07	0.35	0.07
Niobium (Nb)	0.003	<0.04	0.002	0.002	<0.09
Osmium (Os)	<0.001	<0.04	<0.004	<0.008	<0.01
Palladium (Pd)	<0.001	<0.04	<0.004	<0.008	<0.01
Phosphorus (P)	2.5	0.55	0.14	5	0.3
Platinum (Pt)	<0.001	<0.04	<0.004		<0.01
Potassium (K)	3 (MC)	3.1	>6 (MC)	4.5	8 (MC)
Praseodymium (Pr)	0.001	<0.04	<0.004	0.001	<0.01
Rubidium (Rb)	0.15	0.05	0.06	0.1	0.3
Samarium (Sm)	0.002	<0.04	<0.004	<0.008	<0.01
Scandium (Sc)	<0.006	0.05	0.007	0.3	0.03
Selenium (Se)	0.003	0.6	0.008	0.05	0.02
Silicon (Si)	2.5	2	4 (MC)	18	7 (MC)
Silver (Ag)	< .0001	<0.04	<0.004	0.1	<0.009
Sodium (Na)	(MC)	8.5	3.5 (MC)	77 (MC)	7 (MC)
Strontium (Sr)	5	0.65	2	0.3	7 (MC)
Sulfur (S)	(MC)	4 (MC)	7 (MC)	10.5	(MC)
Tantalum (Ta)	0.003	0.7	<0.004	<0.008	<0.01
Tellurium (Te)	<0.001	<0.04	<0.004	<0.008	<0.01
Terbium (Tb)	<0.001	<0.04	<0.004	<0.008	<0.01
Thallium (Tl)	<0.001	<0.04	<0.004	<0.008	<0.01
Thorium (Th)	<0.001	<0.04	<0.004	<0.004	<0.01
Tin (Sn)	0.04	0.04	0.006	0.6	0.01
Titanium (Ti)	0.5	0.25	0.5	3	0.5
Tungsten (W)	0.002	0.07	0.01	0.08	0.03
Uranium (U)	0.06	0.07	<0.004	0.004	0.004
Vanadium (V)	0.015	0.06	0.005	0.01	0.007
Ytterbium (Yb)	0.001	<0.04	<0.004	<0.008	<0.01
Yttrium (Y)	0.002	0.002	0.001	0.001	0.004
Zinc (Zn)	0.12	0.5	0.35	0.06	0.15
Zirconium (Zr)	0.3	0.06	0.008	0.006	0.015

*(MC) - Major Component, present in concentration that exceeded upper analytical quantification limits.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

and lead to serious problems of leaching of soluble materials from the lower shale formations. They also note that sour water decanted from the product oil will pose a disposal problem. Ringrose et al. (1976) found oil shales tended to be enhanced in arsenic, mercury, and selenium and, to a lesser degree, in fluorine, lithium, and molybdenum over the surrounding soils. Dean (1976) noted seven elements of particular environmental interest in oil shale samples--arsenic, boron, cadmium, fluorine, mercury, antimony, and selenium. These are present in 1-ppm ranges but are volatilized during pyrolysis or concentrated in the spent shale.

Bates and Thoem (1979) led a review of environmental impacts from oil shale. Elemental concentrations of raw shales, process waters, and spent-shale leachates are summarized in Table 9. Of prime interest are the relatively high levels of boron, barium, chlorine, fluorine, sodium, silicon, and strontium in leachates. In addition, surface runoff waters from spent oil shale test plots contained higher levels of all test elements, and bicarbonate, chloride, and sediment.

Reed et al. (1976) found both alkaline and acid leaching processes in use during uranium milling. Wastes from the acid process had a pH of 1.5 to 2.0 and contained calcium, sodium, magnesium, and iron cations and chloride and sulfate anions with small amounts of other elements. Alkaline leach-process waste solutions contained fewer elements. A cited analysis shows the alkaline-leach mill-tailings effluent to be high in uranium, sulfate, carbonate, bicarbonate, thorium, and sodium. Reed et al. found that magnesium, copper, manganese, barium, chromium, molybdenum, selenium, lead, arsenic, vanadium, iron, cobalt, nickel, zinc, thorium, uranium, and radium was leached from the ore and appeared in the effluent streams. These effluents are discharged to tailings ponds. Excess water may be discharged directly to streams following a neutralization process. They also cited a number of cases where ground-water contamination from tailings had occurred. The primary pollutants cited were selenium, nitrates, and sulfates.

In a series of reports on inactive mill-tailing sites, Ford, Bacon and Davis Utah, Inc. (1977a, 1977b, 1977c and 1977d) found ground waters near mill tailings to be enhanced in barium, chromium, selenium, lead, arsenic, vanadium, and cadmium. In the case of cadmium, high ambient levels were observed throughout the area, and the tailings contribution was believed to be insignificant.

These studies indicate that a large number of elements and inorganic ions may be released into the environment by energy resource development activities. The major ions--calcium, magnesium, sodium, sulfate, chloride, and bicarbonate--are likely to be affected. Cyanides, nitrates, and ammonia are also common products of energy development activities. Minor elements imported by at least two researchers at elevated or potential problem levels in coal, oil shale, uranium ore, or their process streams are:

Aluminum
Antimony
Arsenic

Barium
Boron
Bromine

Cadmium
Chromium
Copper

Fluorine
Gallium
Iron

Lead
Lithium
Manganese

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

TABLE 9. TRACE ELEMENTS IN OIL SHALE RETORT WATERS AND SPENT-SHALE LEACHATES

Element	Retort Waters (mg/l) (from Bates and Thoen 1979)					Spent-Shale Leachates (mg/l)					Surface Runoff (mg/l)	
	Tosco II	In Situ Tosco II	LETC	LLL	Fischer Assay	Parahoe Indirect	Soil	Parahoe	Tosco II	Surface Retorts	Tosco II Spent-Shale Plot	USBM Spent-Shale Plot
Aluminum (Al)	1.0	0.007	0.004-0.036	0.047			0.05	0.05	--	--		
Antimony (Sb)	0.09	0.26	0.26-10	1.8	0.0-4.2	1.0	0.02	<0.007	0.005	0.1		
Barium (Ba)		0.03	0.002-0.081	<0.3		2.0	0.07	0.12	--	4.0		
Beryllium (Be)	0.44	0.26	0.26-8.8		0.55-2.8	5.0	0.005	0.01	--	--		
Boron (B)			0.019-0.66	0.1		0.009	1.14	0.8-1.6	4.6	2-12		
Bromine (Br)		0.001	--		0.00		--	<0.04	--	--		
Cadmium (Cd)			0.41-36		1.4	>10.0	166.4	421.4	--	--	140.4	61.1
Calcium (Ca)			0.023			2.0	4.28	526	--	42-114	42.0	62.6
Chlorine (Cl)	0.007	0.012	0.011-0.037	0.08	0.004	0.03	0.01	<0.04	--	--		
Chromium (Cr)	0.005	0.37	0.002-0.65	0.23	0.002-0.005	<0.04	0.02	0.05	--	--		
Cobalt (Co)	0.16	0.003	0.003-0.016		0.16	0.2	1.31	11.9	--	--		
Copper (Cu)	0.3	0.49	14-54		2.6-3.5	7.0	0.01	0.03	--	3.4-60		
Fluorine (F)	5.7	0.01	0.49-77	14.0	1.0	5.0	0.01	0.01	16.6	--		
Iron (Fe)	<0.002	0.01	0.01-0.37	0.0	0.2	0.005	0.01	6.8	3.5	3.5-91	53.4	19.2
Lead (Pb)	0.006	--	0.004-0.75			>10.0	190.3	7.74	--	--		
Lithium (Li)			3.2-350		0.02	0.3	0.05	<0.14	--	--		
Magnesium (Mg)	0.019	0.023	0.023-0.14			<0.01		<0.003	--	--		
Manganese (Mn)		0.01	0.01-0.39	0.024	0.006-0.13	0.1						
Mercury (Hg)	0.006	0.47	0.056-0.47		0.034-2.3	20.0	0.01	834.0	77.2	10-625	38.7	45.1
Molybdenum (Mo)	0.03	0.26	0.26-2.6		0.1-3.1	>10.0	0.02	0.03	0.02	0.05		
Nickel (Ni)			3.4-70			0.1	0.02	8.1	--	--		
Potassium (K)	0.096	0.005	0.003-0.10	1.7		>10.0	0.001	5.591	10,700	165-2,100	47.6	27.3
Selenium (Se)			1.7-48		43.0	>10.0	712	10.4	--	--		
Silicon (Si)			8.3-1300	20.0	0.06	>10.0	2.77	0.28	--	--		
Silver (Ag)			0.003-0.48									
Sodium (Na)			14-310									
Strontium (Sr)			0.11-100									
Sulfur (S)			0.010-4.6									
Tin (Sn)			0.004-11	<0.03	0.0	0.03	0.04	0.15				
Uranium (U)		1.2	0.037-0.47	14.4	0.045-0.2	0.4	0.04					
Vanadium (V)	0.002	0.04	0.008-0.39									
Zinc (Zn)	0.045	5.0										
Zirconium (Zr)	0.003	0.02										

LLL = Lawrence Livermore Laboratory
LETC = Laramie Energy Technology Center
USBM = U.S. Bureau of Mines

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

Mercury
Molybdenum

Nickel
Selenium

Silver
Strontium

Sulfur
Thorium

Uranium
Vanadium
Zinc

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

POSSIBLE ORGANIC POLLUTANTS

The pollution of water resources by organic compounds derived from energy development activities is of great concern. Little is actually known about what compounds are released, their fate, or their effect on the environment. The extreme difficulty in conducting organic analysis has discouraged most researchers and has largely limited monitoring efforts to organic carbon, phenols, oils and grease, and similar substances. Goldstein and Yung (1977) and Gehrs (1976) reviewed available data and identified the compounds and compound classes presented in Table 10 as being present in oil shale and coal-hydrogenation process waters and products. In some cases, particularly ammonia and phenol, the compounds are major by-products of the process.

Gehrs (1976) states that the phenols are high in acute toxicity but generally low in known deleterious chronic effects and bioaccumulation potential. Although little is known about the thiophenes and aromatic amines, it appears the opposite is true; they seem to have high chronic toxicity and bioaccumulation potential with low removal and degradation rates. Observed concentrations of these compounds and assessment of waste-water removal effectiveness are shown in Table 11.

Wachter and Blackwood (1978) determined concentrations of several selected organic chemicals in simulated rainfall leachates from coal stockpiles of Montana coal. They found no compound present at a concentration above 100 parts per billion (ppb) and concluded that levels of organic toxins entering adjacent waterways could be from 6 to 11 orders of magnitude less than established criteria.

In a recent study, Pellizzari (1978) reported the elemental and organic chemical substances found in process and effluent streams in several western energy developments. More than 50 samples from oil shale process waters, tars and condensates from the low-Btu gasification of coal, and water and tar samples from in situ coal gasification experiments were analyzed for both volatile and semivolatile organic compounds.

Pellizzari's (1978) methods provided for the analysis for volatile and semivolatile compounds to levels of 1 ppb [1 microgram/kilogram ($\mu\text{g}/\text{kg}$)]. The procedure was quantitative for volatile compounds with solubilities less than 2 percent in water and boiling points less than 220°C and for semipolar compounds with solubilities less than 10 percent and boiling points less than 150°C . The technique was not quantitative for highly water-soluble compounds (e.g., acetonitrile, formaldehyde, etc.). The procedure for semivolatile compounds gave quantitative recoveries for organic acids, neutral compounds, and bases for compounds with boiling points greater than 60°C and less than 270°C . Compounds with zwitterions (dipolar ions) were not recovered and analyzed, nor were compounds with boiling points greater than 275°C .

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 10. COMPOUNDS AND ORGANIC COMPOUND CLASSES IDENTIFIED IN OIL SHALE
AND COAL HYDROGENATION PROCESS STREAMS AND PRODUCTS
(Goldstein 1977; Gehrs 1977)

DROPPED
HEAD
BEGIN
SECTIONS
HERE

acridine	m,p-cresol	olefins	dibenzothiophene
hydroxylbenzaldehyde	creosotes	dicycloparaffins	benzo- def dibenzothiophene
n-alkanes	cyanide	tricycloparaffins	naphthobenzothiophene
nitrosamines	thiocyanide	perylene	methylbenzothiophene
ammonia	sulfo cyanides	benzo(g,h,i)perylene	dimethylbenzothiophene
aniline	ethane	phenol	methyl dibenzothiophene
1-2 benzantracenes	acetylaminoflourene	C ₂ -phenols	tetrahydrobenzothiophene
7,12-dimethyl	benzofuranols	C ₃ -phenols	methylthiophene
benz(a)anthracene	dibenzofurans	biphenol	dinaphthothiophene
benzo-a-anthracene	hydroxybenzofuran	diphenol	toluene
phenanthrene	H ₂ S	m,p, and o,-ethylphenols	m,p-ethyltoluene
3-4 benzphenanthrenes	dihydric	3-ethyl-5-methylphenol	o,p, and m-toluidines
fluoranthene	formaldehyde	benzothiophenols	o-xylene
benzene	indans	acetophenones	m,p-xylene
alkyl benzenes	indanol	a-picoline	2,3-xylene
dihydroxylbenzene	indenes	propane	2,4-xylene
C ₁ -dihydroxylbenzene	indenol	propylene	2,5-xylene
C ₂ -dihydroxylbenzene	lactones	pyrenes	2,6-xylene
1,2,3-trimethylbenzene	lutidines	benzo-a-pyene	3,4-xylene
1,2,4-trimethylbenzene	methane	pyridine	3,5-xylene
1,3,5-trimethylbenzene	naphthalene	C ₂ , C ₃ , and C ₄ -pyridine	2,4-xylydine
benzoic acids	1-ethylnapthalene	2-ethylpyridine	2,5-xylydine
butenes	2-ethylnapthalene	quinoline	2,6-xylydine
n-butane	1-methylnapthalene	isoquinoline	
i-butane	2-methylnapthalene	methylquinoline	
carbazole	acenaphthenes	N-methylsuccinamide	
chrysenes	acenaphthylenes	tetralins	
coumarone	benzonitrile	benzothiophene	
methylcoumarones	paraffins	benzylthiophene	
o-cresol	monocycloparaffins		

Pellizzari's data demonstrate several important features. First, each sample has a very unique organic composition. Second, most of the commonly identified compounds are present in very small (<100 ppb) quantities. Third, the state-of-the-art analyses still have many compounds identified only in the form "C_nH_n isomer" and many others as isomers of only somewhat better defined compounds (e.g., benzofuran isomer). Finally, the number of compounds identified is staggering.

Tables 12 and 13 summarize these data, indicating the number of times a compound was reported as exceeding an arbitrary limit of 100 ppb (column N in the tables) and the maximum value reported for that compound in each of six sample groupings. The groupings represent: oil shale process effluents (O.S.); tars and condensates from low Btu coal gasification of Rosebud coal (LBtu); in situ gasification well samples (Pre I.S.); samples from several stages of processing of both the Gillette (Gillette) and Hanna II (Hanna) in situ gasification studies; and postgasification well samples (Post I.S.).

Few organics were present in the pregasification in situ experiments ("native" ground-water samples). Benzene, benzylamine, toluene, n-hexanal, and isomers of dimethylphenol, cresol, methylthiophene, and C-alkylbenzene were reported, but at concentrations less than 400 ppb. Ethyl acetate, however, reached a concentration of 630 ppb. Well samples collected following

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 11. OBSERVED CONCENTRATION RANGES OF ORGANIC CHEMICALS FROM COAL-HYDROGENATION STREAMS AND RELATED WASTE-WATER REMOVAL EFFECTIVENESS (Gehrs 1976)

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

Compound Class	Anticipated Range (mg/l)	Waste Water Removal Effectiveness (%)
Phenols	1,000 - 10,000	99.9
Aromatic amines	100 - 1,000	30 - 50
Monoaromatic hydrocarbons	10 - 100	90 +
Thiophenols	1 - 10	
Polycyclic hydrocarbons	0.1 - 1	30 - 80

in situ gasification contained a few more organic compounds, which were present in generally larger concentrations than in pregasification samples. Ethyl acetate, ethyl formate, formic acid, in-pentanel, and cresol and phenol isomers were present in the higher concentrations; a few other compounds were present at concentrations less than 200 ppb. Of the compounds found in postgasification well waters, phenol and dimethyl phenol isomers are of special concern. Phenol has been selected by the U.S. Environmental Protection Agency (EPA) as a priority point-source effluent-discharge toxic pollutant and is a suspected carcinogen (Christensen and Fairchild 1976). Several dimethyl phenol isomers (xlenols) are known carcinogens or neoplastens (produce benign tumors); a dimethyl phenol isomer was reported present at a concentration of 1,500 ppb in a postgasification well sample. Many of the more complex phenols, cresols, and formic-acid compounds are also carcinogens and most have toxic qualities as well. The various process streams, tars, and other samples contained both more varieties and higher concentrations of organic compounds than well-water samples. Semivolatile compound concentrations in product waters and tars during in situ gasification were particularly high, in a few cases saturating the analytical capability to quantify them. A C₂-alkyl analine isomer, C₂-alkyl benzene, cyanobenzene, a methylbenzofuran isomer, cresol isomers, o-cresol, naphthalene, phenol, C₂- and C₄-alkyl phenol isomers, an ethylphenol isomer, a dimethylphenol isomer, methylpyridine, and 2,3-benzothiophene all exceeded a concentration of 10,000 ppb in one or more samples. Of these, naphthalene, phenol, and several dimethylphenol isomers are suspected carcinogens (naphthalene is a neoplasten) and have been reported as toxic to aquatic organisms at concentrations of 10,000 ppb or less (Christensen and Fairchild 1976).

In order to reduce the lengthy lists of Tables 12 and 13, compounds occurring in 15 or more of Pellizzari's (1978) samples at concentrations greater than 100 ppb are indicated in Table 14. Naphthalene commonly occurred in both sets of analyses, is a suspected carcinogen, and has an aquatic toxicity of 1 to 10 ppm (Christensen and Fairchild 1976). The cresol and phenol compounds are common, usually fairly toxic, and often carcinogenic. Benzene, ethylbenzene, and toluene are suspected carcinogens with aquatic toxicities in the 10 to 100 ppm range. The cresols, phenols, and naphthalene are of particular concern since they may also occur in high concentrations.

BEGIN
LAST LINE
OF TEXT

3/8"

TOP OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 12. MAXIMUM VALUES OF SEMIVOLATILE ORGANIC COMPOUNDS IDENTIFIED IN
WESTERN ENERGY RESOURCE DEVELOPMENT SAMPLES (Pellizzari 1978)

DROPPED
HEAD;
BEGIN
SECTION
HERE

Compound	N	Concentration in ppb (µg/kg)					
		O.S.	LBtu	Pre I.S.	Gillette	Hanna	Post I.S.
ethyl acetate	16			630	1,320	6,800	1,725
biphenyl acetylene	1					153	
isopropyl alcohol	1				522		
benzaldehyde	2				8,914		
C ₂ -alkyl benzaldehyde isomer							
C ₃ -alkyl benzaldehyde	1				4,200		
C ₃ -alkyl benzaldehyde	1				360		
dimethylbenzaldehyde isomer	2				9,970	640	
3,4-dimethylbenzaldehyde	1				150		
ethyl benzaldehyde isomer	1				157		
tolualdehyde	1				430		
benzylamine	5	377			190	3,460	
aniline	9		497		150	3,540*	
C ₂ -alkyl aniline isomers	4		154		1,460	24,200	
methylaniline isomers							
anisole	4					1,075	
anthracene or phenanthracene	2		188				
benzene	37			275		156	
C ₂ -alkyl benzene	4				10,225		
C ₃ -alkyl benzene isomers	4				3,214*	693	
C ₄ -alkyl benzene	9			2,270	1,760*	4,420	
C ₄ -alkyl benzene isomers	5				2,981	540	
C ₅ -alkyl benzene isomers	11			3,080	3,215	1,140	
C ₆ -alkyl benzene isomers	4			2,310	2,180	340*	
C ₇ -alkyl benzene isomers	2			630	580		
C ₈ -alkyl benzene isomers	1			5,100			
C ₉ -alkyl benzene isomers	3			2,370		330	
n-butylbenzene	3				2,050*	113	
cyanobenzene	3				11,231*	1,350	
ethylbenzene	5				1,210	320	
triethylbenzene isomer	1				5,500		
trimethylbenzene isomers	8				8,391	5,100*	
d ₅ -nitrobenzene	1				146		
n-pentylbenzene	9			590*	1,839	370	
n-popylbenzene	2			760*	420		
benzofuran	7		880		9,150	2,300	
dibenzofuran	6		4,030		4,391	640	
methylbenzofuran isomers	11		7,770		11,231*	2,907*	
benzoic acid	4	493			417		
dimethylbenzoic acid isomers	1					325	
C ₈ H ₈ O ₂ isomer	1					259	
C ₆ H ₈ O isomer	3					1,340	
C ₆ H ₁₂ O isomer	1				170		
C ₆ H ₁₂ O (Ketone ?)	1				169		
C ₇ H ₉ N	3				762	1,267	
C ₇ H ₁₀ O isomer	57		110		7,921	172	
C ₇ H ₁₂ O isomer	1					180*	
C ₇ H ₁₄ isomer	1		234				
C ₇ H ₁₄ O isomer	1					218	
C ₇ H ₁₄ O ₂ acid	1					244	

BEGIN
LAST LINE
OF TEXT

(continued)

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 12. (Continued)

DROPPED
HEAD,
BEGIN
SECTION
HERE

Compound	Concentration in ppb (µg/kg)						
	N	O.S.	LBtu	Pre I.S.	Gillette	Hanna	Post I.S.
C ₈ H ₁₁ N isomer	11	621			7,936	740	
C ₈ H ₁₂ O isomer	3				4,231		
C ₈ H ₁₄ O isomer	1		760				
C ₈ H ₁₆ isomer	1				150		
C ₈ H ₁₆ O isomer	2				5,260		
C ₉ H ₁₃ N isomer	4	422			761		
C ₉ H ₁₄ O isomer	1	175					
C ₉ H ₁₈ isomer	3					380	
C ₉ H ₁₈ O isomer	2				1,310		
C ₉ H ₂₀ isomer	1					1,100	
C ₉ H ₂₀ O isomer	1				421		
C ₁₀ H ₁₂ isomer	9		380		1,921	1,780	
C ₁₀ H ₁₅ N isomer	1				3,762		
C ₁₀ H ₁₆ isomer	1					425	
C ₁₀ H ₂₀ isomer	4				550	280	
C ₁₀ H ₂₂ isomer	3					11,000	
C ₁₁ H ₁₂ isomer	3		480		540		
C ₁₁ H ₁₂ O isomer	1		1,410				
C ₁₁ H ₂₄ isomer	8		420		3,989	1,040*	
C ₁₁ H ₂₄ isomer	7		230		5,620	1,160	
C ₁₁ H ₁₄ isomer	2				371	640	
C ₁₂ H ₁₄ isomer	1				230		
C ₁₂ H ₁₆ isomer	7		2,410*		2,424	880*	
C ₁₂ H ₂₄ isomer	6		2,100		3,850*	1,720	
C ₁₂ H ₂₆ isomer	2					420	
n-C ₁₂ H ₂₆ isomer	1				1,240		
C ₁₃ H ₁₀ O isomer	2		1,190		550		
C ₁₃ H ₁₈ isomer	6		5,130		490	113	
C ₁₃ H ₂₆ isomer	7		2,050		2,050*	2,500	
C ₁₃ H ₂₈ isomer	6		410		540	513	232
C ₁₄ H ₁₀ isomer	1				560	340	
C ₁₄ H ₁₄ isomer							
C ₁₄ H ₂₀ isomer	11		370		1,470	780	
C ₁₄ H ₂₈ isomer	6		590*		5,100	440	
C ₁₄ H ₃₀ isomer	1					640*	
C ₁₅ H ₂₂ isomer							
C ₁₅ H ₂₈ isomer	4					620	
C ₁₅ H ₃₀ isomer	7		760*		2,982*	500	
C ₁₅ H ₃₂ isomer	7				1,760*	960*	
n-C ₁₅ H ₃₂ isomers	1					860	
C ₁₆ H ₁₄ isomers	1				1,410		
C ₁₆ H ₃₂ isomers	2		2,310		250*		
C ₁₆ H ₃₄ isomers	6				1,930	1,660	
n-C ₁₆ H ₃₄ isomers	1				2,190		
C ₁₇ H ₃₆ isomers	4				2,370	632	
C ₁₈ H ₃₆ isomers	4				2,030	840	
n-C ₁₈ H ₃₈ isomers	2				170	440	
C ₁₉ H ₄₀ isomers	2				170	520	
n-C ₁₉ H ₄₀ isomers	2				140	3,100	
C ₂₀ H ₄₂ isomers	1					780	

(continued)

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

45

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 12. (Continued)

DROPPED
HEAD;
BEGIN
SECTION
HERE

Compound	Concentration in ppb (µg/kg)						
	N	O.S.	LBTu	Pre I.S.	Gillette	Hanna	Post I.S.
C ₂₀ H ₄₂ isomers	3		11,000			3,140*	
n-C ₂₀ H ₄₂ isomers	5		510		5,160	1,960	2,615
C ₂₁ H ₄₄ isomers	2					200*	
n-C ₂₁ H ₄₄ isomers	1		1,710				
C ₅ H ₁₀ O ₂ carboxylic acid	2					510	
C ₆ H ₁₂ O ₂ carboxylic acid	1					143	
cresol isomers	43	779	35,000	189	89,600*	270,000*	1,572
O-cresol	2		2,534			17,760*	
n-decanal	1					440	
n-decane	7		129	635		3,520	
n-dodecane	10		6,560		2,315	5,040	
n-heptadecane	2					280*	
n-hexadecane	4		4,250*			1,600	139
n-nonadecane	7		12,110		2,100	1,540	
n-octadecane	3				333	320	
n-pentadecane	6		3,590*		3,989*	1,240	
n-tetradecane	10		12,270		2,976	3,540	
n-tridecane	13		12,100		2,730*	5,100*	127
n-undecane	9		1,650		5,976	3,747	
decanoic acid	1					1,600	
n-eicosane	2					3,100	
n-heneicosane	3					1,140	
methyl cresyl ether	1				476		
dimethyl ether	1				135		
flourene	8		470		8,200	580	
ethyl formate	13		1,200		720		930
formic acid	1						306
phenyl-n-heptane							
n-heptanol	2	165				280	
heptanoic acid	1				376		
n-heptanoid acid	1				145	8,870	
2-heptanone	1					225	
n-hexanal	2			120		160	
phenyl-n-hexane	6		3,150		342*	1,100	
2-hexanone	2					275	
cyclohexanone	1					210	
indan	8		940*		6,921	3,740	
alkyl indan isomer	5		2,370*		660	560	
methylindan isomer	5		3,590		510	3,540*	
dimethylindan isomer	6		1,570		130	1,160	
tetramethyl indan	1		1,550				
trimethylindan isomer							
pentamethylinden	6		6,270		8,800*	100	
pentamethylinden isomer	1				4,190		
tetramethyl indanone isomer	1		100				
indene	10		7,100		1,440	2,540	
methylindene isomer	10		8,250*		450	2,907*	
indole	1					275	
methyl ethyl ketone	1					246	
naphthalene	16		21,350		72,500	16,400	

(continued)

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 12. (Continued)

DROPPED
HEAD.
BEGIN
SECTION
HERE

Compound	Concentration in ppb (ug/kg)						
	N	O.S.	L8tu	Pre I.S.	Gillette	Hanna	Post I.S.
acenaphthalene	10		4,380		2,560	2,040	
alkyl naphthalene isomers	2				876		
C2-alkyl naphthalene isomers	7		3,879		1,410*	5,540	
C3-alkyl naphthalene isomers	8		7,810		1,560	580	
C4-alkyl naphthalene isomers	2		430			1,200	
C5-alkyl naphthalene isomers	2					180	
ethylnaphthalene isomers	8		4,030		1,570	3,400	
methyldihydronaphthalene isomers	2		2,810			340*	
methylnaphthalene isomers	13		17,200		9,200	5,720	124
dimethylnaphthalene isomers	10	199	18,230		8,200*	6,420	115
trimethylnaphthalene isomers	1		470				
isopropylnaphthalene isomers	1		1,780				
n-hexylnitrile	1					250	
n-pentylnitrile	1					462	
n-propionitrile	1					130	
n-nonanal	3					820	
n-nonane	5				520	2,267	
phenyl-n-nonane	1		1,550*				
n-hexylnitrile	1					250	
n-octanal	1					1,140	
n-octane	1					800	
phenyl octane	1					280*	
phenyl-n-octane 2			230			340*	
n-octanoic acid	5	115				1,230	120
n-pentanal	1						505
n-pentanoic acid	6				138	4,825	
isopentanoic acid	3				400		
2-methylpentanoic acid	2					1,150	
3-methylpentanoic acid	1					725	
2-pentanone	3					1,170	
3-methyl-2-pentanone	2					110	
cyclopentanone							
2-alkyl cyclopentanone	1					650	
2-methylcyclopentanone	3					2,075	
3-methylcyclopentanone	1					2,100	
dimethylcyclopentanone	1					375	
phenol	31	461	41,000		89,600*	270,000*	232
C2-alkyl phenol isomer	20	337	11,000		105,100	14,500	
C3-alkyl phenol isomer	15		1,000		10,500	296,725	2,560*
C4-alkyl phenol isomer	8		110		8,200*	296,725*	
C5-alkyl phenol isomer	1				470*		
tri-butylphenol isomer	2					4,760	
di-sec-butylphenol isomer	1					3,440*	
tri-sec-butylphenol isomer	5				360	3,840	
ethylphenol	2		110		4,770*		
ethylphenol isomer	23	321	5,000		8,800*	74,700	279
methyl ethylphenol isomer	1				33,625		
dimethylphenol isomer	34	1,011	28,800	360	48,000*	7,800	1,510
trimethylphenol isomer	1					180	
acetophenone	3				9,327		

(continued)

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

TABLE 12. (Continued)

Compound	Concentration in ppb (ug/kg)						
	N	O.S.	LBtu	Pre I.S.	Gillette	Hanna	Post I.S.
biphenyl	8		8,210		1,390	680	
methylbiphenyl	1					540	
methylbiphenyl isomers	2		410		960*		
biphenylene	6		290		6,777	300	
alkylpyridine isomer	3	176			1,010		
C-alkyl pyridine isomer	3				329	740	
C-alkyl pyridine isomer	1				8,140		
C-alkyl pyridine isomer	1				1,020		
ethylpyridine isomer	1				4,050		
methylpyridine isomer	2				20,000	196	
3-methylpyridine isomer	1					250	
4-methylpyridine isomer	1					100	
dimethylpyridine	2				4,200	499	
dimethylpyridine isomer	5				6,310	973	
trimethylpyridine isomer	2	762					
pyrrole	2					270	
quinoline	2				5,160*	1,087	
2-alkylquinoline	1					100	
C-alkylquinoline							
tetrahydroquinoline	1				487		
methylquinoline isomer	6		210*		4,770*	3,000	
dimethylquinoline isomer	1				326		
methylstyrene isomer	2					280*	
benzothiophene	1					200	
2,3-benzothiophene	7		1,880		11,482	227	
toluene	13		465	117	130	2,667	150
ethyltoluene	4		120*		3,667*	1,540	
ethyltoluene isomer	5				3,820	3,747	
toluic acid isomer	1					490	
xylene isomers	6				760	1,760	
m-xylene	1					1,334	
o-xylene	2					5,040	
p-xylene	2					1,400	

*More than one compound identified in analysis.

Columns indicate the maximum reported concentration in ppb (ug/kg) for all samples in: 1) oil shale effluents (O.S.); low Btu gasification of Rosebud coal effluents and tars (LBtu); in situ pre-gasification (Pre I.S.); process streams and tars from in situ gasification experiments at Gillette (Gillette) and Hanna (Hanna), Wyoming; and well-water samples collected after in situ gasification well-water samples (Post I.S.). N indicates the number of samples in which the indicated compound exceeded the 100 ppb level; values less than 100 ppb were not reported.

BEGIN
LAST LINE
OF TEXT

3/8"

48

EPA-287 (C/n.)
(4-76)

PAGE NUMBER

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 13. MAXIMUM VALUES OF VOLATILE ORGANIC COMPOUNDS IDENTIFIED IN
WESTERN ENERGY RESOURCE DEVELOPMENT SAMPLES (Pellizzari 1978)

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

Compound	Concentration in ppb (ug/kg)						
	N	O.S.	LBtu	Pre I.S.	Gillette	Hanna	Post I.S.
acemaphthene	3					1,690	
acetaldehyde	2					2,033	
methylphenylacetylene	1					119	
acetone	17	200	259		2,226	9,330	181
aniline	3		1,143			1,330*	
benzaldehyde	1					1,340	
benzene	25	134	1,457	192	4,318	7,670*	150
C-alkylbenzene isomer	1		222				
C ₂ alkylbenzene isomer	1					180	
C ₃ alkylbenzene isomer	7		144		835	1,200	
C ₄ alkylbenzene isomer	10		250		1,068	2,100	
C ₅ alkylbenzene isomer	29		390*		716	2,400	
C ₆ alkylbenzene isomer	4					1,000*	
C ₇ alkylbenzene isomer	2					1,200	
C ₇ H ₁₅ benzene	1		1,180				
cyanobenzene	3	235				2,670	
methyl cyanobenzene isomer	2					830	
methyl butylbenzene isomer	1					1,200	
n-butylbenzene	1					3,800*	
ethyl benzene	15		160		1,423*	1,660	
f-diethylbenzene	1					3,800*	
diethylbenzene	1					1,800	
dimethylethylbenzene isomer	2				100	540	
n-heptyl benzene	1				100*		
isobutyl benzene	1		111*				
isobutyl benzene isomer	1					193	
diisopropyl benzene isomer	1					400*	
methylpropyl benzene isomer	1					152	
tetramethyl benzene isomer	1					1,400	
1,2,3,5-tetramethyl benzene	1				182		
1,2,4,5-tetramethyl benzene	1				168		
1,2,3-trimethyl benzene	10		361		833	3,000	
1,2,4-trimethyl benzene	11		234*		928	6,670	
1,3,5-trimethyl benzene	4		139			622	
n-pentyl	3				125	800*	
dimethylbenzimidazole isomer	1		571				
benzofuran	13		267				
dibenzofuran	1					167	
dimethyl benzofuran isomer	7		657		2,532	400	
4,7-dimethylbenzofuran	2					1,000	
methyl benzofuran isomer	8		186		2,371	3,000	
2-methyl benzofuran	4		391			150	
t-butanol	1	130			250*	1,330*	
2-methylbutanal	1					115	
3-methyl-2-butanone	1				3,259*		
m-cresol	2					2,000	
o-cresol	3					10,000	
p-cresol	2					4,000	
o-cymene	1		111*				
C ₅ H ₃ isomer	1					127*	

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA,
OUTSIDE
DIMENSION
FOR TABLES
AND ILLU-
STRATIONS

(continued)

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 13. (Continued)

DROPPED
HEAD
BEGIN
SECTION
HERE

Compound	N	Concentration in ppb (ug/kg)					
		O.S.	LBtu	Pre I.S.	Gillette	Hanna	Post I.S.
C ₅ H ₁₀ isomer	1						
C ₅ H ₁₂ isomer	1		154		750*		
C ₆ H ₁₂							
C ₇ H ₁₂ isomer	2					115	
C ₇ H ₁₄ isomer	2					240	
C ₇ H ₁₂ O isomer	1					131*	
C ₈ H ₁₆ isomer	2					330	
C ₉ H ₁₈ isomer	5				191	3,000*	
C ₉ H ₁₈ O isomer	1		660*				
C ₉ H ₂₀ isomer	2					3,000*	
C ₁₀ H ₁₂ isomer	5				785	840	
C ₁₀ H ₂₀ isomer	12		234*		892*	3,864*	
C ₁₀ H ₂₂ isomer	7		200		668*	3,500*	150
C ₁₁ H ₁₂ isomer	2					800	
C ₁₁ H ₁₄ isomer	3				209		
C ₁₁ H ₂₂ isomer	7		190		2,171	3,650	
C ₁₁ H ₂₄ isomer	7		660*		122	2,200	260
C ₁₂ H ₁₆ isomer	2					312	
C ₁₂ H ₂₄ isomer	5		1,040		217	1,700*	
C ₁₂ H ₂₆ isomer	7		1,860		480*	1,520*	
C ₁₃ H ₁₆ isomer	1					400	
C ₁₃ H ₂₀ isomer	1					700	
C ₁₃ H ₂₆ isomer	4				480*	140	
C ₁₄ H ₂₈ isomer	4		340		933	110	
C ₁₄ H ₃₀ isomer	4		1,070		100*	200	
C ₁₅ H ₂₆ isomer	1		1,720				
C ₁₅ H ₃₀ isomer	1		1,860				
C ₁₅ H ₃₂ isomer	3		1,250		110	670	
C ₁₆ H ₃₂ isomer	1					1,700	
C ₁₆ H ₃₄ isomer	1				126		
n-decane	8		134		1,572	1,910*	
2,6 dimethyl-n-decane	1					420	
n-hexadecane	1					2,660	
7-methyltridecane	1					910	
n-pentadecane	1				200		
n-tetradecane	7		185		625	2,330	
n-tridecane	1					900	
1-decene	1					1,400*	
1-tetradecene	2					1,000	
1-tridecene	9		1,267*		675*	5,000	
2-decanone	1				100		
3-dodecane	1		139				
n-dodecane	11		560		1,915	7,600*	
nundecane	11		320		1,227	400	
2,6,10-trimethyl dodecane	1					110	
1-dodecene	1					200	
menthyl-n-propylether	1					210	
n-heptane	1					240	
2-heptanone	5	244	195			151*	
isopropylcyclohexane	1					520	

(continued)

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 13. (Continued)

DROPPED
HEAD:
BEGIN
SECTION
HERE

Compound	Concentration in ppb (ug/kg)						
	N	O.S.	LBtu	Pre I.S.	Gillette	Hanna	Post I.S.
n-hexane	7		400		250		
1-phenyl hexane	2					500	
trimethylcyclohexane isomer	2					1,920*	
cyclohexanone	1					170	
2-hexanone	8		202		604	626	
3-hexanone	6		117			300*	
2-methylcyclohexanone	1					330	
3-methylcyclohexanone	1					134	
indan	16		247		2,766	3,200	
3-alkyl indane isomer	1					900	
dimethyl indan isomer	4		1,110		107*	1,000	
methyl indan isomer	7		114		300	1,230*	
C ₂ -alkyl indan	2		390*				
C ₃ -alkyl indan isomer	2		189			800*	
trimethyl indan	3				128*	140	
1-methylindane	1					1,400	
2-methylindane	1					1,100*	
indene	16		375	140	833	3,158	
dimethylindene isomer	1					1,660	
3,3-dimethylindene	1					800	
methylindene isomers	8		889		317	4,200	
methyl ethyl ketone	11	152			498	13,230	
methyl isopropyl ketone	5				196	7,670*	
methyl-n-propyl ketone	1					125	
C ₆ H ₁₂ O Ketone isomer	1				107		
naphthalene	22		7,250		13,920	23,684	100
dimethylnaphthalene isomers	4					4,000	
2,6-dimethyl-1,2,3,4-tetrahydro-naphthalene	1				210		
ethylnaphthalene isomer	2					1,670	
methylnaphthalene isomers	1						279
α-methylnaphthalene	17		3,160		2,505	3,200	111
β-methylnaphthalene	17		3,162		2,826	4,200	169
methyl-dihydronaphthalene isomer	4		171*			670	
3-methyl-1,2-dihydronaphthalene	1				116		
acetonitrile	7				1,246	1,340	
ethane nitrile	2					6,456*	
n-hexylnitrile	1					4,000	
isobutyronitrile	1					127*	
n-pentylnitrile	4				331	1,670*	
n-butyronitrile	4					1,000	
α-methylbutyronitrile	1					167	
propane nitrile	2					1,492	
propionitrile	5				175	2,000	
n-nonane	4				200	1,400	
3-methylnonane	1					360	
2-nonanane	2		156		100		
nonene isomer	1					440	
n-octane	4				170	820	
cyclooctatetraene	1					1,400	

(continued)

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 13. (Continued)

DROPPED
HEAD,
BEGIN
SECTION
HERE

Compound	Concentration in ppb (ug/kg)						
	N	O.S.	LBtu	Pre I.S.	Gillette	Hanna	Post I.S.
2,3-dimethyloctane	1				180		
2,6-dimethyloctane	1					421	
2-methyloctane	1				140		
2-octanone	4	126	188			130	
3-methylpentanal	2		209				
n-pentane	2		167				130
methylcyclopentane	1	680					
2-pentanone	15	123	260		846	4,700	
3-pentanone	5				297	2,330	
cyclopentanone	4					1,670	
dimethylcyclopentanone isomer	1					830	
methylcyclopentanone	1					100	
2-methylcyclopentanone	5					3,000	
2-methyl-3-pentanone	2					1,549	
3-methyl-2-pentanone	1		466				
4-methyl-2-pentanone	2					167	
phenol	4					6,700	
C ₃ -alkylphenol isomers	3					800	
C ₄ -alkylphenol isomer	1					537	
biphenol	3					5,330	
ethylphenol isomer	1					4,200	
2-ethylphenol	2					1,000	
3-ethylphenol	1					5,000	
dimethylphenol isomer	1					1,330	
2,4-dimethylphenol	1					5,330	
methylethylphenol	1					690	
trimethylphenol isomer	1					237	
acetophenone	3		660*		100	340	
biphenylene	2					1,700*	
propanol	1				300		
isopropanol	1					367*	
n-methylpyrazole	1	177					
pyridine	6	185			707	2,420	
dimethylpyridine isomer	6					2,170	
methylpyridine isomer	4					1,000	
2-methylpyridine	1					143	
3-methylpyridine	2					670*	
methylethylpyridine isomer	1					300*	
C ₂ -alkylpyridine isomers	1	240					
pyrrole	9				111	6,661	
dimethylpyrrole isomer	2					1,330	
2-methylpyrrole	3					2,000	
3-methylpyrrole	3					2,330	
styrene	10				107	2,200	
2-alkylstyrene	1					120	
ethylstyrene isomer	1					439	
dimethylstyrene isomer	1					2,200	
methylstyrene isomer	3		356			1,100*	
amethylstyrene	5					2,500	
dimethyl sulfide	1					668	

(continued)

BEGIN
LAST LINE
OF TEXT

3/8"

52

PAGE NUMBER

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

TABLE 13. (Continued)

DROPPED
HEAD:
BEGIN
SECTION
HERE

Compound	N	Concentration in ppb (ug/kg)					
		O.S.	LBtu	Pre I.S.	Gillette	Hanna	Post I.S.
thiophene	5				241	620	
C ₃ -alkylthiophene isomers	2				1,202*	200	
C ₄ -alkylthiophene isomers	1				718*		
benzothiophene	3					1,340*	
dimethylthiophene isomers	4				2,000*	1,130*	
ethylthiophene isomer	2				1,423*	157*	
2-isopropylthiophene	1					200	
methylthiophene isomers	2			120		556*	
2-methylthiophene	8		134		150	1,000	
3-methylthiophene	7		107		170*	445	
ter-butylthiophene isomer	1					200	
trimethylthiophene isomer	1					1,330	
2,3,4-trimethylthiophene	2					420	
toluene	22	300	1,334	150	1,554	2,145	
m-ethyltoluene	9		278		367	3,864*	
o-ethyltoluene	8		148		571	2,800	
p-ethyltoluene	2					3,500*	
p-or methyltoluene	3		189		175	620	
o-propyltoluene	1					800	
p-propyltoluene	2				167	1,500*	
m-p-xylene	21		210		2,000*	4,848	
o-xylene	19		312		1,215	1,670	

*More than one compound identified in analysis.

Columns indicate the maximum reported concentration in ppb (ug/kg) for all samples in: 1) oil shale effluents (O.S.); low Btu gasification of Rosebud coal effluents and tars (LBtu); in situ pre-gasification well-water samples (Pre I.S.); process streams and tars from in situ gasification experiments at Gillette (Gillette) and Hanna (Hanna), Wyoming; and well-water samples collected after in situ gasification (Post I.S.). N indicates the number of samples in which the indicated compound exceeded the 100 ppb level; values less than 100 ppb were not reported.

In summary, there are little data regarding identification of organic pollutants in energy resource development processes. Post-in situ gasification water samples analyzed by Pellizzari (1978) contained cresol and phenol isomers; one dimethylphenol isomer was reported at a level of 1.5 ppm. Various process tars and waters also contained high levels of cresols, phenols, naphthalenes, and other compounds that are both toxic and carcinogenic. Although reported concentrations rarely exceeded established toxic levels in water samples for a given compound, they frequently approached these levels. If a chemical class (e.g., phenols) were grouped, concentrations would cumulatively exceed toxic levels.

Reed et al. (1976) reviewed uranium milling. They found that the major organics present were kerosine, amines, and isodecanal. These are primarily associated with the acid leach process during solvent extraction and are commonly discharged in the tailing effluents.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA:
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 14. COMPOUNDS OCCURRING MORE THAN 15 TIMES AT CONCENTRATIONS
OF 100 ppb OR MORE (Pellizzari 1978)

DROPPED
HEAD
BEGIN
SECTIONS
HERE

Volatile Compounds	Number of Occurrences	Semivolatile Compounds	Number of Occurrences
C ₅ -alkyl benzene isomers	29	C ₇ H ₁₀ isomer	57
*benzene	25	*cresol isomer	43
*naphthalene	22	benzene	37
*toluene	22	*dimethylphenol isomer	34
<u>m</u> and <u>p</u> -xylene	21	*phenol	31
<u>o</u> -xylene	19	ethylphenol isomers	23
C ₄ -alkyl benzene isomers	18	C ₂ -alkyl phenol isomer	20
α-methylnaphthalene	17	dimethylnaphthalene	20
β-methylnaphthalene	17	ethyl acetate	16
*acetone	17	*naphthalene	16
indan	16	C ₃ -alkyl phenol isomers	15
indene	16		
*ethylbenzene	15		
2-pentanone	15		

*Listed as suspected carcinogens (Christensen and Fairchild 1976)

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

PRESENT WATER-MONITORING SYSTEM

Monitoring to assess the impact of western energy resource development on water quality is presently being conducted by a multitude of Federal, State, local, and private organizations. The primary data collector is the U.S. Geological Survey (USGS). USGS maintains more stations and for longer than any other organization (Iorns 1965). Their data are entered into two Federal computer data bases, WATSTORE, maintained by USGS, and STORET, maintained by the U.S. EPA. Much of the WATSTORE data is eventually entered into STORET by USGS. However, ground-water data and daily records are usually not available in STORET. STORET is widely used by other Federal and State agencies to store their own data as well. STORET is the primary data base from which western energy water quality impact assessments are made.

Most existing water-monitoring stations and networks were designed for purposes other than assessment of energy resource development impact. Some stations have only been maintained for a year or two, others are located in areas of little concern (with regard to energy impact), and still others monitor only one or two parameters. Ground-water quality records are noticeably scarce, and attempts to establish monitoring networks of any size have only recently been initiated. An inventory of available STORET data was made to identify those stations currently in operation with data records for several years for a large number of parameters (Environmental Monitoring and Support Laboratory Las Vegas, 1977). Using data from these stations and an empirical approach, Thomas et al. (in press) attempted to define long-term trends for 20 parameters in selected major rivers impacted by energy resource development. They found data records for many parameters to be inadequate to detect trends at even the "best" stations.

Wolman (1971) conducted a comprehensive survey to determine trends in the quality of U.S. rivers. He concluded that existing data were generally inadequate to identify trends in water quality. Specifically, existing data were insufficient in volume and the parameters being measured were inadequate to identify trends in river quality.

Steele et al. (1974) defined areal and temporal changes based on temperature and conductivity data from 88 USGS stations. They found that for other parameters the water-quality records available in computerized form were generally insufficient in terms of areal coverage, frequency of sampling, and period of record for their purposes. Cleary (1977) complained that, with few exceptions, the assemblage of river water-quality data by State and Federal agencies is of limited usefulness in discerning trends or for other comparative purposes.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

55

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

On a more specific basis, Judy and Gartner (1977) reviewed water-quality data in the Yellowstone-Tongue River (Montana) area. They state that water-quality or stream-flow data have been collected at 176 sites, but most of these have only one year or less of available data. They further note that much known data are not available in STORET. Thomas et al. (in press) also noted this data lack and found published USGS ground-water records for Piceance Creek (Weeks and Welder 1974) unavailable in STORET.

Table 15 (Melancon et al. 1979a) presents a summary from STORET of pertinent energy resource development impact parameters monitored with some degree of frequency at stations in the San Juan River Basin. Biological and organic analysis data are almost totally lacking. Most trace elements are sampled on an intermittent or quarterly basis by USGS. A wide variety of analytical species (i.e., dissolved, total, etc.) were measured for many parameters. The difference in the elemental analyses reported at USGS and Colorado State stations makes simultaneous use of data from the two sources to detect trends nearly impossible. These data are typical of those reported for western streams. They are generally inadequate both in available parameters, and frequency of collection for meaningful trend analysis.

Data quality control is yet another concern. In working with data in the San Juan Basin it was noted that some USGS dissolved elemental values were consistently higher than comparable total elemental values reported by Colorado State Department of Natural Resources. Telephone calls to the respective agency laboratories were unable to resolve this problem. Several colleagues working with data in the White and Yampa River Basins have found discrepancies between data published in USGS Quality of Surface Water Papers and STORET listings. "Wild" data, such as a reported pH of 170, have been noted in the STORET records on numerous occasions. Because large order-of-magnitude fluctuations are common in western rivers, (Thomas et al. in press) distinguishing between "wild" data and valid outliers poses a major problem. STORET also does not discriminate between composite, grab, or averaged samples and provides no method to identify what kind of sample a data entry represents.

Western energy resource development may impact the aquatic environments through a multitude of pathways and with a wide variety of pollutants. It is only the effect of these impacts on living things, particularly man (including emotional issues), that is of concern. Yet monitoring of these impacts is not a routine portion of many monitoring programs.

Biological parameters are seldom monitored on a continuous basis. An exception occurs at NASQAN stations where phytoplankton and periphyton samples are collected on a monthly and quarterly basis, respectively. Phytoplankton samples are analyzed for total cells found, identification of the three most numerous forms, and the percent of the total community that each represents. Periphyton samples are collected quarterly, and dry and ash free weights determined. Chlorophyll a and b content is also determined in periphyton samples (Ficke and Hawkinson 1975). Bacteria analyses (fecal coliform and fecal streptococci) are also conducted monthly at NASQAN stations and at other selected sites.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

56

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

TABLE 15. (Continued)

Parameter	USGS Station Numbers										Colorado Station Numbers																							
	09341200	09343000	09343300	09343400	09344300	09344450	09346000	09346400	09347200	09349800	09352900	09354500	09357300	09358900	09357500	09363500	09364500	09365000	09366500	09379500	000119	000102	000068	000069	000067	000081	000066	000104	000065	000103	000064	000063	000062	
00945 Sulfate, total (mg/l)	10	8	6	6	8	6	6	6	6	10	6	12	8	6	12	9	12	12	52	4	52	52	4	4	6	5	4	5	4	5	5	4	5	5
00950 Fluoride, dissolved (mg/l)	10	8	6	6	8	6	6	6	6	10	6	12	8	6	12	9	12	12	24	4	52	52	4	4	6	5	4	5	4	5	4	5	4	5
00951 Fluoride, total (mg/l)	10	8	6	6	8	6	6	6	6	10	6	12	8	6	12	9	12	12	24	4	52	52	4	4	6	5	4	5	4	5	4	5	4	5
00955 Silica, dissolved (mg/l)	10	8	6	6	8	6	6	6	6	10	6	12	8	6	12	9	12	12	52	4	52	52	4	4	6	5	4	5	4	5	4	5	4	5
01000 Arsenic, dissolved (ug/l)	1	2	1	1	1	1	2	6	4	1	4	3	1	1	1	7	2	2	2	6	6	4	4	4	4	4	4	4	4	4	4	4	4	4
01001 Arsenic, suspended (ug/l)																																		
01002 Arsenic, total (ug/l)																																		
01005 Barium, dissolved (ug/l)																																		
01010 Beryllium, dissolved (ug/l)																																		
01015 Bismuth, dissolved (ug/l)																																		
01020 Boron, dissolved (ug/l)	10	8	6	6	8	6	6	4	9	4	4	4	6	8	2	6	12	12	36	24	4	4	4	4	4	4	4	4	4	4	4	4	4	4
01022 Boron, total (ug/l)	1																																	
01025 Cadmium, dissolved (ug/l)	1	2	1	1	1	1	2	2	1	1	1	4	1	1	1	5	2	3	2	6	4	4	4	4	4	4	4	4	4	4	4	4	4	4
01027 Cadmium, total (ug/l)																																		
01030 Chromium, dissolved (ug/l)																																		
01032 Chromium, hexavalent (ug/l)	1	2	1	1	1	1	1	1	1	1	1	1	2	1	1	3	2	3	4	6	4	4	4	4	4	4	4	4	4	4	4	4	4	4
01034 Chromium, total (ug/l)																																		
01037 Cobalt, total (ug/l)																																		
01040 Copper, dissolved (ug/l)	1	2	1	1	1	1	2	2	1	1	1	4	1	1	1	7	2	3	2	6	4	4	4	4	4	4	4	4	4	4	4	4	4	4
01042 Copper, total (ug/l)																																		
01045 Iron, total (ug/l)																																		
01046 Iron, dissolved (ug/l)	10	8	6	6	8	6	6	4	9	4	12	4	6	2	12	9	3	12	12	2	4	4	6	6	4	6	4	4	4	4	4	4	4	4
01049 Lead, dissolved (ug/l)																																		
01051 Lead, total (ug/l)	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	5	1	1	2	6	4	4	4	4	4	4	4	4	4	4	4	4	4	4
01054 Manganese, suspended (ug/l)																																		
01055 Manganese (ug/l)	10	1	2	1	1	1	2	2	9	4	2	2	1	1	1	9	6	1	1	1	6	4	4	6	6	4	5	4	5	4	5	5	5	5
01056 Manganese, dissolved (ug/l)																																		
01060 Molybdenum, dissolved (ug/l)																																		
01062 Molybdenum, total (ug/l)																																		
01065 Nickel, dissolved (ug/l)																																		
01075 Silver, dissolved (ug/l)	1	2	1	1	1	1	1	1	1	1	1	1	4	1	1	2	1	1	1	1	1	2	2	3	3	2	2	2	2	2	2	2	2	3
01077 Silver, total (ug/l)																																		
01080 Strontium, dissolved (ug/l)																																		
01085 Vanadium, dissolved (ug/l)																																		
01092 Zinc, total (ug/l)																																		

(continued)

(continued)

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

TABLE 15. (Continued)

Parameter	USGS Station Numbers												Colorado Station Numbers											
	09341200	09343000	09343300	09343400	09344300	09344450	09346000	09346400	09347200	09349800	09352900	09354500	09355500	09357300	09358900	09357500	09363500	09364500	09365000	09366500	09368000	09379500	000119	
01100 Tin, dissolved (ug/l)																								
01105 Aluminum, total (ug/l)																								
01120 Gallium, dissolved (ug/l)																								
01125 Germanium, dissolved (ug/l)																								
01132 Lithium, total (ug/l)																								
01135 Rubidium, dissolved (ug/l)																								
01145 Selenium, dissolved (ug/l)																								
01146 Selenium, suspended (ug/l)																								
01147 Selenium, total (ug/l)																								
01150 Titanium, dissolved (ug/l)																								
01160 Zirconium, dissolved (ug/l)																								
01300 Oil-grease severity																								
Total coliform MP/NECND (100 ml)	2	1	1	1	2	4	1	4	2	4	12	12	2	2			24	12						
Total coliform MP/ICONE (100 ml)					4	6	6	12	6	24	6						24	12						
Fecal coliform MP/NECNR (100 ml)	1	2	1	1	1	4	6	6	12	8	12	6					6	24	12	12				
Fecal coliform MP/NECND (100 ml)																								
Residue suspended at 180°C (mg/l)																								
Residue dissolved at 180°C (mg/l)																								
Dissolved solids SUM (mg/l)	10	8	6	6	8	6	6	10	6	12	6	12	12	12	12	12	52	4	52	24				
Dissolved solids (tons/day)	10	8	6	6	8	6	6	10	6	9	6	12	12	12	12	12	52	4	52	52				
Mercury, dissolved (ug/l)																								
Mercury, suspended (ug/l)																								
Mercury, total (ug/l)																								
Suspended sediment concentrate (ug/l)	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Suspended sediment	4	24	3	12	12	6	4	12	6	12	6	12	6	12	12	12	52	4	52	24				
Suspended sediment discharge (tons/day)	4	24	3	12	12	6	4	12	6	12	6	12	6	12	12	12	12	52	4	52	24			

Parameters are listed by STORET code, name, form, and unit.
*Indicates each turbidity unit; 1 = intermittently sampled.
MFNECND = membrane filter, immediate, endo agar.
MPICONE = most probable number, confirmed test (second stage).
MFN-FCBR = membrane filter, MF-C Broth (media grown in).
MPNECND = most probable number, EC medium.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

Monitoring of macrobenthic organisms, fishes, macrophytes, or other biologic forms is conducted on a sporadic basis, usually for a special study. The data are seldom readily available to researchers other than the original collectors.

Phytoplankton, although comprising a large proportion of the aquatic biota in standing or sluggish water, are usually a small component of the biologic community in western streams. Indeed, a large proportion of the phytoplankton in western streams is, in reality, detached periphyton. Taylor et al. (in press) have investigated phytoplankton and water-quality relationships in U.S. lakes. They found few usable relationships on individual species or genera levels, although community structure has shown correlations with water-quality parameters. Indices of organic contamination or presence of toxins in rivers are primarily based on periphyton forms. Therefore, the effort presently placed on phytoplankton analyses in flowing streams would be better spent in determining benthic algae community composition.

Recent studies with macrobenthic forms in western rivers have indicated their potential for use in monitoring the effects of changes in water quality. Again, community-structure studies rather than individual forms appear to hold the most promise as monitoring tools. Such efforts are considered to be in a developmental stage at this time.

Use of fish as biological monitors does not appear to be widespread and is usually limited to species inventories or bioaccumulation studies. Biological monitoring of effluent streams using caged populations is an increasing practice. Use of natural populations for monitoring is further complicated by restrictions imposed by State agencies on collecting fish.

Biological monitoring is the most direct method of assessing impact of western energy development upon aquatic resources. Development of economical, standardized methodologies for biological monitoring should be encouraged. Although biological monitoring, except for the algae forms, may not be practical at a water-quality station, nearby areas should be suitable for such purposes.

In summary, present water-quality monitoring networks generally contain stations suitably situated to monitor the impact of energy resource development upon western surface-water quality. Existing ground-water quality monitoring networks are generally quite local in extent and very recent in implementation. The parameters presently being measured vary widely and, with few exceptions, are not sampled frequently enough to identify trends. Data on many parameters of interest, continuous records, and ground-water data are not generally available in STORET. Data outliers and quality control are concerns when utilizing the data.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

60

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

NETWORK DESIGN FOR MONITORING ENERGY DEVELOPMENT IMPACT

MONITORING NETWORK DESIGN CONSIDERATIONS

In order to assess the impact of western energy resource development upon water quality, water-quality trends, both temporal and spatial, in regional water resources must be determined. When trends indicate a potential problem, the next component of the assessment is to locate its cause.

Design of surface-water monitoring or water-quality surveillance systems and networks have been discussed by many researchers in recent years (NUS Corporation 1970; Beckers et al. 1972; Beckers and Chamberlain 1974; Sherwani and Moreau 1975; Lettenmaier 1975; Lettenmaier 1978; Berndt 1975; Lewis 1976). All agree that careful definition of monitoring objectives is a necessary first step in designing a network. The primary objectives of a surveillance- or enforcement-oriented network are to collect data to effectively enforce compliance with water-quality standards either through prevention or abatement (Beckers et al. 1972). Measurement of extremes (pollution events) is an objective, and sampling frequency is a function of the duration and number of expected events. Sampling stations are usually located within or near pollution sources (Beckers et al. 1972; Beckers and Chamberlain 1974; Sherwani and Moreau 1975). The primary objective of a trend-monitoring network is to characterize the water quality of a water body, usually through mean values (Lettenmaier 1975; Ward 1973). They are designed to collect data adequate to identify trends in water quality over time or space; detection of pollution events is not a primary consideration. Stations should be sited outside of the immediate influence of a point-source pollutant (Lettenmaier 1975). Although either type of network may satisfy the objectives of the other, the different considerations for sampling frequency and station location make it probable that a system designed for surveillance purposes will not provide adequate data for trend detection and vice versa.

The network design itself consists of specification of the parameters to be measured, the frequency of sampling, and the number and locations of sampling sites (Sherwani and Moreau 1975).

Selection of parameters should not be made capriciously. Careful consideration must be given to ambient concentrations, expected changes from activities in the area, impacts from present or projected concentrations and loadings, the analytical methodologies available, sampling considerations, and available resources. The desirability of monitoring a given parameter must be weighed against the difficulties in collecting, preserving, and analyzing the samples. Conversely, the ease with which some measurements can be made should be weighed against the value of the resultant data.

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
LAST LINE
OF TEXT

3/8"

61

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

The design is always constrained by limitations on available resources of time, money, manpower, or technology. Therefore, networks should be optimized to obtain the maximum amount of pertinent information for the least (or available) amount of effort or cost. Often the design limit is determined by the number and nature of the water-quality laboratory analyses that can be performed given finite resources. It is necessary to compromise between the sampling frequency at any given station, the number of stations, and the number and nature of the parameters for which analyses are required. For any single parameter, the question is how to distribute the samples obtained. Should a large number of stations be sampled relatively infrequently or vice versa? Although they approach the problem from different theoretical bases and with different objectives, nearly all of the reviewed researchers conclude that the more efficient system consists of few stations with relatively large numbers of samples from each.

A monitoring network should be able to detect changes in stream water quality but will usually rely on other work to determine the causes of such changes. Beckers et al. (1972) state that "definition of local problems is not a monitoring (network) function; it requires, in general, the implementation of a special purpose, intensive water quality survey . . ." and that a monitoring network ". . . will be employed to ascertain the status of the river basin as a whole . . . it is not intended that the system be used to determine the precise cause and extent of water quality degradation." Sherwani and Moreau (1975) add that ". . . accidental or intentional spills cannot be dealt with economically by a monitoring network and should not influence its design." Berndt (1975), speaking on design of an enforcement monitoring system, also states that "where a problem area is discovered, repeated short surveys must be undertaken to identify the specific nature of the problem." Site specific data are available from stations that are required by mining lease regulations and research activities in the resource development areas. These data may be used in conjunction with the network to aid in determining the causes of observed trends. It is important to remember that trends exist in both time and space. The objective of assessing the impact of western energy resource development upon water quality is best satisfied by designing a monitoring network that would identify trends in water quality over a period of 3 to 4 years.

PARAMETER SELECTION

The long and seemingly all-inclusive list of parameters to be derived from western energy resource development activities is too large for each to be included in a monitoring effort. Some method is needed to reduce the total amount of effort required for sample analysis.

Kinney et al. (1979) identified 44 physical and chemical parameters as priority A (high priority) parameters for monitoring oil shale development impact on surface waters. These were: (1) Parameters that had, in the past, equalled or exceeded acceptable limits with respect to beneficial water uses and whose ambient levels in surface waters are likely to be altered by activities associated with the development and operation of an oil shale industry to the point where further impairment of beneficial water uses will

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
LAST LINE
OF TEXT

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

result; (2) those parameters for which water-quality criteria must be established for receiving waters based on tolerance levels of important, sensitive species in those waters and whose ambient levels in receiving waters are likely to be altered by activities associated with the development and operation of an oil shale industry to the point where the biota may be adversely impacted; or (3) parameters whose measurement is essential for purposes of interpreting water-quality data.

Melancon et al. (1979a, 1979b) used a similar set of criteria to identify 34 "must-monitor" parameters for monitoring energy impact on water quality in the San Juan River Basin and 38 "must-monitor" parameters in the Tongue-Powder River Basin. Table 16 presents a listing of identified priority physical/chemical parameters for monitoring energy resource development and identifies those presently being monitored at NASQAN stations. Even these seemingly similar criteria did not provide identical parameter lists.

Monitoring of chemicals in the aquatic environment poses a question as to which form should be measured--total*, dissolved or filterable**, suspended or nonfilterable, or other forms. Various arguments for and against measuring each form are still being discussed (Hem 1970).

In natural waters elements can occur as free ions; as inorganic ion pairs or complexes; in organic complexes, colloids, microcrystalline suspension, precipitates, and sediments; adsorbed onto colloids, seston, or sediments; and as part of biological organisms. Strumm and Morgan (1970) discuss the various states, equilibriums, and interactions at great length. Most toxicity studies have been carried out on metal aquo ions. Data available for elements in suspension or as precipitates are meager and insufficient to conclude whether dissolved or suspended metals are more toxic or whether the toxicity of the various states is dependent upon the metal (Clarke 1974). Elemental levels are affected by the physical, chemical, and biological conditions in the water and in many cases are poorly understood.

In general, excluding sediment and biological analyses, water-quality measurements are either ionic, total, or dissolved (filterable). In some cases suspended (nonfilterable) measurements are conducted. It would be highly desirable to have information on both total and dissolved (and, by subtraction, suspended) forms, but available resources rarely permit this during routine monitoring operations. U.S. Environmental Protection Agency criteria (U.S. Environmental Protection Agency 1976b) are based on the total concentration of a substance because an ecosystem can produce chemical, physical, and biological changes in the element's state that may be

*The total quantity of a given material present in an unfiltered water sample regardless of the form or nature of its occurrence (i.e., dissolved, suspended, adsorbed, etc.). This value is approximated by "total recoverable" analyses, which determine the amount of material that is an analytically detectable form (U.S. Geological Survey 1977).

**Dissolved or filterable forms are those that pass through a 45-micron pore-size filter of a material that does not chemically affect (including by sorption) the parameter being investigated (U.S. Geological Survey 1977).

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

63

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 16. HIGH PRIORITY PHYSICAL/CHEMICAL PARAMETERS AND PARAMETERS
PRESENTLY SAMPLED AT NASQAN STATIONS

DROPPED
HEAD
BEGIN
SECTIONS
HERE

	Kinney et al. 1979	Melancon et al. 1979a (San Juan)	Melancon et al. 1979b (Tongue-Powder)	NASQAN M-Monthly Q-Quarterly C-Continuous
Alkalinity, total		X	X	
Aluminum, dissolved	X			
Aluminum, total	X		X	
Ammonia, total as N		X	X	M
Arsenic, total		X ^a	X ^a	Q
Beryllium, total			X	
Bicarbonate ion	X	X	X	M
Biological oxygen demand, 5-day		X ^b	X ^b	
Boron, dissolved	X			
Boron, total		X	X	
Cadmium, total		X	X	Q
Carbon, total organic		X ^b	X ^b	M
Calcium, dissolved		X	X	M
Chlorides, dissolved	X	X	X	M
Chromium, total		X ^a	X ^a	Q
Specific conductance	X	X	X	C
Copper, dissolved	X			Q
Copper, total	X	X	X	Q
Cyanide, total	X	X ^a	X ^a	
Flow	X	X	X	C
Fluorides, dissolved	X		X	M
Hardness	X			M
Iron, dissolved	X			Q
Iron, total	X ^a	X ^a	X ^a	Q
Lead, dissolved	X			Q
Lead, total	X ^a	X ^a	X ^a	Q
Magnesium, dissolved	X	X	X	M
Magnesium, total	X			
Manganese, dissolved	X			Q
Manganese, total	X	X ^a	X ^a	Q
Mercury, total	X ^a	X ^a	X ^a	Q
Molybdenum, dissolved	X			
Molybdenum, total		X	X	

(continued)

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

TABLE 16. (Continued)

	Kinney et al. 1979	Melancon et al. 1979a (San Juan)	Melancon et al. 1979b (Tongue-Powder)	NASQAN M-Monthly Q-Quarterly C-Continuous
Nickel, dissolved	X			
Nickel, total			X	
Pesticides	X ^a	X	X	
Phenols	X	X	X	
pH		X	X	M
Phosphorus, total		X ^a	X ^a	M
Potassium, dissolved	X	X	X	M
Oxygen, dissolved		X	X	M
Selenium, total		X ^a	X ^a	Q
Silicon, dissolved	X			M
Silicon, total	X			
Sodium, dissolved	X	X	X	M
Solids, dissolved total	X	X	X	M
Solids, total dissolved	X			
Sulfate, dissolved	X	X	X	M
Suspended sediments, total	X	X	X	M
Suspended sediments, fixed	X			
Temperature	X	X	X	C
Turbidity	X			M
Vanadium, dissolved		X		
Zinc, dissolved	X			Q
Zinc, total		X		
Nitrate + nitrate - N				M
Cobalt				Q
Total Kjeldahl nitrogen				M

^aDetermine in both water and bottom-sediment samples.

^bDetermine in sediment samples only.

BEGIN
LAST LINE
OF TEXT

3/8"

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD.
BEGIN
SECTIONS
HERE

detrimental to organisms living in or using the water. In this report, this rationale is generally followed for those parameters that are likely to cause toxic effects. For the major ions (calcium, magnesium, sodium, sulfate, chloride, and bicarbonate) and some other parameters, dissolved determinations are recommended. Where available, the use of specific ion sensors or similar electrodes is encouraged, especially if continuous measurements are possible. However, few of these sensors are sufficiently reliable or free from interferences to use with much confidence in natural waters, and backup analytical methodologies should also be employed.

The major ions--calcium, magnesium, sodium, sulfate, chloride, and bicarbonate--are likely to be affected by energy resource development activities. High levels of calcium, sodium, sulfate, carbonates, and chlorides are commonly found in various process and waste streams. Changes in geochemical conditions as the result of mining activities or releases of ground water may be indicated by either increased concentrations or changes in the ionic ratios of surface waters. These six parameters should be measured in the dissolved form. All of these parameters were mentioned by several researchers as potential pollutants from energy development waste disposal.

For purposes of monitoring energy resource development impact on water quality, the following elemental analyses are recommended:

aluminum, dissolved
arsenic, total
boron, total
barium, total
cadmium, total
chromium, total
copper, total
fluoride, ionic

iron, total
mercury, total
molybdenum, total
nickel, total
lead, total
selenium, total
uranium, total
vanadium, total
zinc, total

These elements were selected from those identified as being enhanced in coals, oil shale, uranium ores, or their process streams or wastes. The rationale for each element is presented in Appendix A. Of the elements listed, only barium and uranium were not included on the lists of Kinney (1979) and Melancon (1979a and 1979b).

In addition to the elemental analyses, monitoring of various organic and inorganic compounds will be required. Ammonia and sulfuric acids are both process fluids and by-products of several resource development activities. Hydrogen peroxide is used during in situ uranium extraction but is so reactive and short-lived that monitoring for environmental reasons is not warranted. Cyanides and thiocyanides are compounds common to fuel processing activities. Explosives used in extraction and pollution from uranium tailings commonly increase nitrates and nitrites in waters (Reed et al. 1976). Monitoring for energy development impact on water quality should include collection of data on ammonia, sulfate, cyanide, nitrate, and nitrite concentrations. Bicarbonate and carbonate concentrations, pH, conductivity and, total alkalinity are likely to be affected by releases of alkalis or acid wastes in effluent streams, either directly or through subsequent chemical reaction

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

and should be monitored. Total and dissolved solids concentrations are expected to increase as a result of energy resource development activities and should also be measured.

Pollution by organic compounds produced during extraction, conversion, and refinery operations is of intense concern. Two different approaches to organic pollutant analysis exist; analyses may be made for selected compounds or may attempt to detect and quantify all compounds present. Pellizzari's (1978) data indicate that each sample is unique in its organic composition and that monitoring for individual compounds would not be effective. In addition, monitoring for individual compounds assumes that environmentally hazardous compounds have been identified. In order to obtain data upon which future monitoring requirements can be based, it is recommended that surveys of all organic compounds present in energy resource effluents be made on an annual basis or in conjunction with resource development experiments. The high cost of such analyses--\$2,000 per sample or more--precludes their incorporation into a trend-monitoring network at the present time.

It is recommended that available analytical technology be utilized whenever possible to monitor phenols, oil-in-water, and selected organic compound classes. In particular, phenol and oil-in-water measurements are now possible on a routine basis, and these two parameters should be included at network monitoring stations. Total organic carbon and dissolved organic carbon should also be monitored. Because organic debris can place a large demand upon the oxygen budget, biochemical oxygen demand and total oxygen concentrations are also recommended as monitoring parameters.

Some basic physical and chemical parameters provide data that can be used to analyze the other results. These parameters--flow, pH, conductivity, temperature, and turbidity--should also be routinely monitored. All but turbidity can be monitored effectively on a continuous basis with today's technology. It is recommended that continuous monitoring be accomplished. Dissolved oxygen concentration and biochemical oxygen demand are indicative of the organic pollution loading of a stream and its overall ability to support life. Both parameters should be monitored.

Sediment analyses should also be made at or near water-quality stations. Because metals and organics are sorbed onto sediment particles, they are often more detectable in the sediments than in the water. Analyses should be made for the toxic metals, cyanides, and total organic carbon. Examination for coal particles or specific-gravity separation of coal particles is also recommended. These analyses should be made in the main rivers in areas where fine sediments collect. Semiannual sampling in spring and fall is recommended.

Sediment samples from organic-rich backwater areas should be collected annually. These should represent the upper centimeter or so of the sediment layer. These samples should be split, one portion analyzed for organic content, and the other portion preserved for future analysis. The rationale for this sample is that organic debris often provides a sorption surface for toxic contaminants and helps to concentrate them. In addition, because oil is

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
LAST LINE
OF TEXT

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

known to persist in sediments, these samples may provide evidence of events missed by grab samples.

DROPPED
HEAD
BEGIN
SECTIONS
HERE

Energy resource development threatens to release into the environment chemicals whose effects are long-term, cumulative, and subtle. To completely assess the impact of these chemicals and their potential threat to humans, it is recommended that biological monitoring of natural populations be implemented. Presently, biomonitoring technology is not well developed. Yet it offers the most promise in detecting long-term perturbations in water quality. It may be utilized to integrate parameters over time or as an indication of short-lived, toxic releases that occur between grab-sampling intervals or involve parameters not currently being monitored. Unfortunately, except for observing gross effects (i.e., death of large numbers of individuals), few techniques have been developed for utilizing naturally occurring populations as monitoring tools.

Sampling to determine the bioaccumulation of toxic pollutants should be conducted on an annual or semiannual basis. Bioaccumulation may occur in any biota, but fish are recommended as sample organisms because they are relatively high on the food chain. It is recommended that tissue analysis of fish samples obtained near network water-monitoring stations be conducted for EPA-specified toxic pollutants. Because uptake may vary between species, attempts to obtain the same species previously utilized should be made. Because they are found throughout the area, carp and catfish are recommended as sample organisms. Since the costs of tissue analysis are high, three or four fish should be homogenized, creating a composite sample, prior to analysis. This reduces the chance of obtaining a single abnormal specimen. A portion of each sample should be preserved (freeze-dried or other suitable technique) for possible future analysis.

Samples for fecal coliform and fecal streptococci should be collected and analyzed on a monthly basis.

The collection of phytoplankton samples from western streams is not likely to provide meaningful information, and it is recommended these samples not be obtained at monitoring net stations.

Collection of periphyton samples is recommended, however. Samples should be collected using an artificial substrate and a standardized technique. Analyses should include dry and ash-free determinations for biomass estimates and species identifications and counts. This should be done on a seasonal or semiannual basis.

Collection of macrobenthos samples, using standardized techniques appropriate for each sampling locale, should be conducted from nearby riffle areas on a seasonal or semiannual basis (summer and late fall). Samples obtained should be split and preserved for future reference. If funds permit, community composition (taxonomic enumeration) should be determined to the lowest possible taxonomic level.

BEGIN
LAST LINE
OF TEXT

A similar collection of small fish from a limited (three or less) number of species (dace, gambusia, etc.) should be obtained on an annual or

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

every-other-year basis. At least 50 specimens should be obtained. These should be preserved for future analysis. It is hoped that rapid techniques for identifying tumor development or other evidence of carcinogenic presence will be developed in the near future. These samples would provide a reference "library" to obtain baseline data prior to widespread energy resource development.

In conjunction with the foregoing sampling program, research efforts to develop techniques for biological monitoring of energy resource development impact should be conducted. In addition, because of the presence of numerous known and suspected carcinogens, it is recommended that carcinogenic studies be instituted both using oral doses to standard test animals and using aquatic forms exposed to various organic compound solutions. Field monitoring techniques to determine the extent and increase in cancer or tumor incidence, mutagenic or teratogenic effects, or other long-term consequences of sustained low-level pollutants need to be developed and, once developed, applied. Survey-type biological sampling programs should also be conducted to help establish a reliable data base upon which to build a biological monitoring program. It is emphasized that biological monitoring must be accomplished in conjunction with physical chemical monitoring efforts (and vice versa). Neither monitoring technique will serve all purposes.

Arguments may be made for determining interparameter correlations and if a strong correlation exists between two or more parameters, only monitoring one of them. To successfully use this procedure, the correlation must be strong enough to provide the desired accuracy and precision of the unmonitored parameter and the cause of the relationship must be well understood. If any activity in the area is likely to change the concentration of one parameter preferentially, then the concentration of the other can no longer be safely estimated. Preferential concentrations of many elements are known to occur in the various stages of processing. Extraction methods commonly result in a changed geochemical environment and in shifts in solution susceptibilities. Chemicals used by the energy industry to extract and process both the fuel and necessary water supplies may increase an element's concentration either directly or through subsequent reactions. It is therefore advised that all recommended water-quality parameters be measured at each monitoring station.

It should be stressed that the parameters discussed and recommended are for use in monitoring energy resource development impacts on water quality in Rocky Mountain States. As local conditions or circumstances dictate, other parameters may be of interest. Changes in technology, unsuspected problems, or other considerations may also result in adding to the parameter list. The recommended parameters are those that will permit monitoring of energy resource development impact. The list is not intended to preclude addition of other parameters.

SAMPLING FREQUENCY

BEGIN
LAST LINE
OF TEXT

A major component of sampling system design is the frequency of measurements needed to satisfy the system objectives. Because operational constraints on available resources usually place a limit upon the total number

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

69

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

of analyses, a compromise must be made between the number of stations to be sampled and the number of samples to be taken at each station.

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

It would seem desirable to obtain continuous records of all parameters at all stations. However, few reliable field sensors exist, thus limiting continuous sampling to flow, temperature, conductivity, pH, dissolved oxygen, chloride ion, and a few other parameters. In addition, practical limits exist with regard to handling and storing voluminous records. In most cases continuous records are reduced to daily, weekly, or monthly means. In lieu of continuous sampling, grab samples, representing a discrete point in time, or composite samples, representing an average water sample over a period of time, are necessary.

Sampling frequency for trend monitoring has been addressed directly by Ward (1973), Ward and Nielsen (1978), Lettermaier (1975, 1978), Sanders and Adrian (1978), and, to a lesser extent, Sherwani and Moreau (1975) and Berndt (1975). Most other workers have been concerned with surveillance monitoring (i.e., detection of water-quality criteria violations). In nearly all cases, although different assumptions, objectives, and statistical approaches were used, the conclusion is that the most efficient system is one that has few stations with a relatively large number of samples (for a given parameter).

Before trend analysis can be attempted, the influence of hydrologic variability must be removed from the data. Sherwani and Moreau (1975) state that the sampling frequency to accomplish this is a function of:

- 1) the response time of the system;
- 2) the expected variability of the parameter;
- 3) the half-life and response time of the constituents;
- 4) seasonal fluctuations and random effects (i.e., meteorological, analytical, etc.);
- 5) representativeness under different conditions of flow;
- 6) frequency and duration of short-term pollution events;
- 7) magnitude of response; and
- 8) variability of the inputs.

Frequent sampling of a large lake or large, sluggish flowing river, where the rate of change in concentration of the parameter being investigated is slow, will provide little additional useful information above that provided by a few samples. Conversely, where concentration changes are rapid as may be the case in a small stream, frequent sampling is required. Similarly, highly variable parameters must be sampled more frequently than those with little change in order to attain a desired confidence level. It is apparent that the most efficient sampling frequency will vary from parameter to parameter and

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

70

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

will require various amounts of preexisting data to calculate. As a practical matter, however, these calculations may be unnecessary.

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

Ward (1973) calculated curves of the number of samples per unit time necessary to obtain an allowable error in the calculated mean value for normally distributed, randomly sampled populations with differing standard deviations. The curves are inverse power function hyperbolae that flatten out between 20 and 40 samples per time interval (Figure 15). Ward computed examples using dissolved oxygen, pH, and total dissolved solids data from Colorado rivers and arrived at a figure of 25 samples per year to attain an "accuracy" in which the calculated mean is within 10 percent of the true mean 95 percent of the time.

Lettenmaier (1975) utilized both parametric and nonparametric statistics to evaluate trend-monitoring designs. He found that the flex point in his curves (after which increases in sample numbers contributed relatively little new information) was between 30 and 50 samples per year for a 95 percent confidence level.

To aid in determining an optimum sampling frequency, confidence intervals for a number of parameters were estimated. The confidence interval is that range within which the true mean can be expected to fall within a specified level of confidence. For a 95 percent confidence level, assuming a normal distribution, this interval at a given station and for a given parameter is expressed as:

$$\bar{X} - \frac{1.96\sigma}{\sqrt{n}} \leq \mu \leq \bar{X} + \frac{1.96\sigma}{\sqrt{n}}$$

where n = the number of samples,

$\bar{X}$ = the sample mean,

σ = the standard deviation of the population,

μ = the mean of the population.

Table 17 presents data from three stations. The standard deviation was calculated from available STORET data and is assumed to approximate the standard deviation of the population. (Where n is large, this assumption should be true; where n is small (<30), it is more questionable.) Calculations of the precision term above ($\pm 1.96\sigma/\sqrt{n}$) were made assuming weekly sampling over a one-year period and are tabulated in Table 17.

BEGIN
LAST LINE
OF TEXT

The precision term for the above assumptions reduces to $\pm 0.27\sigma$. Over a three-year period of weekly sampling, the precision term would be reduced to approximately two-thirds of its original value ($\pm 0.16\sigma$). Reducing the sampling rate to biweekly or monthly increases the annual precisions roughly to half again and double the weekly sampling values, respectively

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

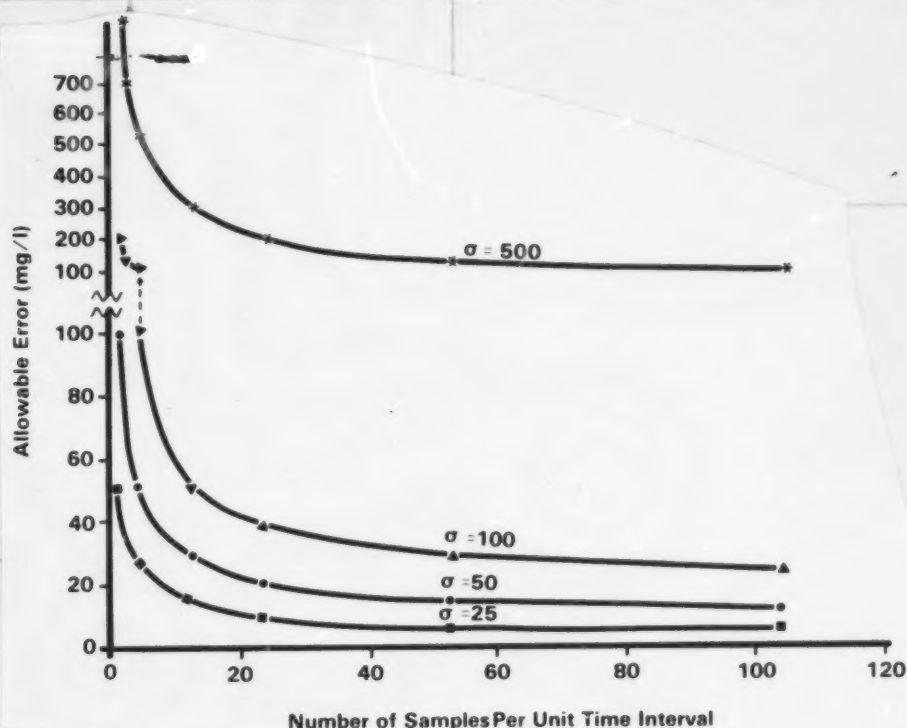


Figure 15. Number of samples vs. allowable error for selected standard deviations (σ) (Ward 1973).

($\pm 0.38\sigma$ for $n = 26$ and $\pm 0.57\sigma$ for $n = 12$). To obtain a 99 percent confidence level, the constant becomes 2.58, and the precision term for weekly sampling over a one-year period becomes $\pm 0.36\sigma$.

Table 17 indicates that a weekly-to-biweekly sampling frequency will provide acceptable precisions for detecting trends in most of the parameters investigated in surface waters. Flow, iron, and arsenic are possible exceptions. Daily flow records would provide markedly improved precisions of ± 87.3 , ± 184.1 , and ± 153.9 cubic feet per second (cfs)* for stations 06308500, 09368000, and 09247600, respectively. USGS maintains daily flow records, so this does not seem an unreasonable monitoring requirement. The iron and arsenic data reflect large variances (standard deviations), but additional sampling for these would require substantial additional resources and would probably not provide a cost-effective return. The cause of these high variances should be examined to determine if they result from sampling or analytical procedures or whether they are the result of natural causes. If the result of sampling or analytical problems, corrective actions may be taken. Similarly, cadmium also has a high variance.

BEGIN
LAST LINE
OF TEXT

*Non-metric units are used in the STORET data base.

3/8"

72

PAGE NUMBER

EPA-287 (Cin.)
(4-78)

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

TABLE 17. STORET DATA STATISTICS FOR SELECTED PARAMETERS AT THREE REPRESENTATIVE STATIONS

Parameter	Tongue River at Miles City, Montana 06308500				San Juan River at Shiprock, New Mexico 09368000				Yampa River below Craig, Colorado 09247600			
	n	mean ($\bar{x}$)	Std dev (σ)	Preci- sion (0.27 σ)	n	mean ($\bar{x}$)	Std dev (σ)	Preci- sion (0.27 σ)	n	mean ($\bar{x}$)	Std dev (σ)	Preci- sion (0.27 σ)
00060 Flow (cfs)	227	597.4	850.7	± 229.7	995	1931.2	1794.0	± 484.4	28	831.9	1500.1	± 405.0
00095 Conductivity (μ mho)	314	830.3	227.1	± 61.3	976	749.6	351.8	± 95.0	34	348.2	120.7	± 32.6
00300 Dissolved oxygen (mg/l)	52	10.5	2.2	± 0.6	109	9.6	1.9	± 0.5	28	98	1.4	± 0.4
00310 Biochemical oxygen demand, 5-day (mg/l)	14	1.9	1.3	± 0.4	46	1.6	1.2	± 0.3	1	1.8	---	---
00400 pH (SU)	314	8.0	0.3	± 0.1	948	7.8	0.4	± 0.1	34	8.0	0.4	± 0.1
00410 Total alkalinity (mg/l)	232	227.3	52.7	± 14.2	589	121.6	33.9	± 9.2	32	106.7	35.6	± 9.6
00915 Calcium (mg/l)	140	62.9	15.5	± 4.2	939	76.7	30.9	± 8.3	32	30.9	10.0	± 2.7
00930 Sodium (mg/l)	314	62.4	24.0	± 6.5	781	70.7	52.7	± 14.2	31	25.8	12.0	± 3.2
00931 Sodium absorption ratio	313	1.5	0.5	± 0.1	925	1.8	1.1	± 0.3	31	1.0	0.3	± 0.1
00945 Sulfate (mg/l)	312	226.6	82.8	± 22.3	926	238.4	152.8	± 41.3	32	64.0	33.8	± 9.1
01002 Arsenic (μ g/l)	17	5.9	7.8	± 2.1	15	14.1	18.7	± 5.1	7	1.3	1.0	± 2.7
01022 Boron (μ g/l)	2	165.0	106.1	± 28.6	606*	110.7	105.1	± 28.4	32*	70.9	31.0	± 8.4
01025 Cadmium (μ g/l)	17	1.4	1.8	± 0.5	20	10.3	29.8	± 8.0	8	0.5	0.5	± 0.1
01040 Copper (μ g/l)	17	3.4	2.5	± 0.7	21	4.3	4.0	± 1.1	8	2.4	2.1	± 0.6
01046 Iron (μ g/l)	79	48.6	50.4	± 13.6	156	17.7	19.7	± 5.3	33	117.0	107.2	± 28.9
01051 Lead (μ g/l)	19	77.2	40.3	± 10.9	15	114.5	69.0	± 18.6	8	75.0	46.3	± 12.5
01145 Selenium (μ g/l)	17	0.5	0.6	± 0.1	15	2.5	1.6	± 0.4	8	0.5	0.8	± 0.2
71900 Mercury (μ g/l)	18	0.09	0.20	± 0.05	15	0.06	0.09	± 0.02	8	0.00	0.00	0
70300 Residue @180°F (mg/l)	267	559.2	167.8	± 45.3	527	548.0	289.4	± 78.1				
70301 Dissolved solids (μ g/l)	110	558.9	169.5	± 43.1	510	446.4	209.2	± 56.5	31	215.4	78.3	± 21.1

*Precisions are based on 95 percent confidence level and an assumed weekly sampling schedule over a one-year period.

However, analytical resolution in most cases is known to be 10 μ g/liter or multiples thereof, so the indicated mean precisions are acceptable.

The statistical procedures utilized thus far assume that the individual data observations are independently distributed, i.e., observation B is not dependent upon the magnitude of observation A. Hydrologic data, including water-quality data, are a continuum and thus, for at least a finite period, do not meet this assumption. Lettermaier (1976) computed correlation coefficients for lag 1 Markov models using daily data. For the data analyzed, these ranged from about 0.75 to 0.9. Using a variety of nonparametric tests for trend detection, he concluded that the point of diminishing returns "for the lag 1 correlation coefficients observed, where little additional power in trend detection was gained for additional sampling effort, appeared to be

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

in the range of 40 to 90 samples per year." In a later work, Lettermaier (1978) concluded that for detection of a step trend "the optimal data collection frequency . . . appears to be in the range from biweekly to monthly" However, he also noted that "an attempt to estimate correlation structures for a number of parameters . . . was largely unsuccessful because the available sampling intervals are too large" and that frequently sampled data are necessary to adequately estimate persistent structure.

Optimum sampling frequency is further complicated by the question of how to distribute the number of samples. Should samples be collected at equal time intervals, on a semirandom basis, or on the basis of hydrographic considerations? In theory, it would be best to maximize the information value of any individual data point by collecting samples during periods of high variability in parameter concentrations. Methods to accomplish this have been proposed by several workers (Berndt 1975; Sherwani and Moreau 1975; Sanders and Adrian 1978). In each case a large amount of preexisting data is required to apply the sophisticated techniques used to determine when to sample.

There are two basic problems with this "stratified sampling" approach. One is that the highest variability in parameter concentration occurs at different times for different parameters and at different stations. The practical considerations of sampling logistics require either considerable compromise, large resources, or both. The second problem is that a paradox exists. If a rigorous statistical design is used to maximize the stratified sampling schedule, a great deal of data is required for the calculations. Moss et al. (1978) note that if the prerequisite design parameters are known with certainty, there is probably no need to collect the data. In order to implement stratified sampling based on variability, even on a less rigorous basis, a large amount of prior knowledge is required.

Stratified sampling is based on one other assumption--that parameter-concentration variability will continue to follow preestablished patterns. Pollutants generated by energy resource development activities may or may not follow historical distribution patterns. The environmental disturbances may be expected to more closely follow the level of mining or processing activity than hydrographic cycles. In addition, stream flows are increasingly subjected to manipulation through operation of dams, diversions, discharges, etc. These manipulations impose additional elements into the naturally occurring flow regimes and parameter concentration patterns.

Data are not presently adequate to determine optimum sampling times except for a few parameters such as temperature and conductivity. Sanders and Adrian's (1978) method requires an extensive period of daily parameter records in order to determine the harmonic components of variability. Such records are generally unavailable although an argument may be advanced for using conductivity to estimate the variability of ionic constituents.

BEGIN
LAST LINE
OF TEXT

Lettermaier (1978) observed that for purposes of trend detection, whether using an independent observation or an autocorrelated data assumption, it is important for data to be collected uniformly in time. The stratified sampling

BOTTOM OF
IMAGE AREA,
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

strategy was generally found to be much less efficient, requiring two to three times as many samples to obtain equivalent confidence levels, than uniform sampling strategies.

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

The advantage of frequently sampling one parameter during periods of low flow highly variable concentration are offset by other parameters that exhibit low variability in concentration under low-flow conditions and large concentration changes during high-flow periods. A fixed sampling interval greatly simplifies logistics. The selection of an interval without a seven-day component will help assure that man's weekly work schedule will not lead to biased data. (In addition, the hour of sampling should not be consistently the same; ideally it would be distributed over the 24-hour period. If this is done, the existence of naturally occurring daily cycles such as those commonly observed for dissolved oxygen, pH, and weather/solar data must be acknowledged and allowed for in data interpretation.) A recommended sampling frequency uniformly spaced over 8- to 13-day intervals will provide between 25 and 50 samples per year and should yield acceptable precisions for subsequent analyses and interpretation.

6-1/2"

NUMBER AND LOCATION OF STATIONS

As previously indicated, the number of stations to be included in a network is more often dictated by available resources than by theoretical considerations. Resource constraints demand a compromise between the number of stations and the frequency of sample collection at each. Nearly all researchers have concluded that the more efficient network consists of relatively few stations with relatively large numbers of samples from each.

Available resources for monitoring energy resource development impact on water quality are not known and will assuredly fluctuate from year to year. For this reason it was decided to select only the minimum number of stations necessary to identify trends in energy resource development areas. Further definition and resolution of the causes of observed trends may be accomplished through use of data from other sources or by intensive survey efforts.

Water-quality monitoring stations in the study area are generally sited on flowing streams. Sampling of lakes or reservoirs requires collection of samples at various depths in the water column to detect vertical variations in parameter concentrations. In most western streams, turbulent flow is expected to homogenize the water column. Thus a single sample can be representative of water quality at that point. (This assumption is not always true and should be tested occasionally at all monitoring streams.) Larger reservoirs also act as settling basins for suspended materials; horizontal gradients may be substantial within the reservoir, and sediments may act as sinks for some materials. These materials are potentially available for reentry into the water with changes in environmental conditions. For trend-monitoring purposes, reservoirs have been avoided as station locations in favor of flowing streams. Although this decision simplifies the monitoring system, it neglects the potential impact of toxic compound buildup in reservoir sediments. Evaluation of reservoirs as sinks for toxic materials should be made as a special study or separate monitoring effort.

BEGIN
LAST LINE
OF TEXT

3/8"

75

PAGE NUMBER

BOTTOM OF
IMAGE AREA,
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

Location of stations for monitoring energy impact trends on water quality must be carefully selected so that water-quality parameter levels will be representative for that water body. Spatial distribution within a water body will differ from parameter to parameter because of differences in their source locations and the transformations they undergo in the environment. Methods to accomplish effective station siting were advanced by many authors (NUS Corporation 1970; Sharp 1971; Beckers et al. 1972; Sherwani and Moreau 1975; Berndt 1975).

Sharp (1971) proposed an approach that determined the approximate center of a stream network by making equivalent stream order numbers at the outlet of each subnetwork approximately equal. A monitoring station would be located at the outlet of each subbasin, and the process reiterated. Beckers et al. (1972) utilized quantitative methods to develop a preliminary design for a surveillance network. They first compute numerical priorities for each stretch of river for each water-quality parameter of interest. From these data, they calculate the preferred location for sampling each parameter.

Sherwani and Moreau (1975) developed a surveillance-station siting technique that first determined the number of stations required to achieve a desired precision based on a normal distribution of variances of parameter concentrations in an area. The first station was chosen so that the excess concentration (the difference between the natural background concentration and that at the end of the mixing zone below a point source) was reduced 50 percent. To locate this site, they determined concentration gradients of parameters of interest, selected the gradient with the greatest rate of decay, and calculated the initial sampling location. The distance between subsequent station spacings were doubled each time. They then use interstation correlations and principal component techniques to reduce the size of the network and obtain the optimum density.

Lettenmaier (1975) presented a very good review of work on sampling system designs. He noted a 1974 study by Sanders in which, following a development utilizing Sharp's (1971) methods to establish macroscopic station locations, Sanders used mixing length theory to determine "microscopic" locales. Sanders found that even when mixing was far from complete, high correlations existed between water-quality parameter concentrations in stream cross sections.

Lettenmaier (1975), in his development of trend-monitoring design, found the network design efficiency to be relatively insensitive to sample station location. In a later paper (Lettenmaier 1978), he recommends a subjective approach to selecting station locations that includes the following:

1. Consideration of using existing stations
2. Location of stations to monitor a substantial proportion of the total runoff from a river basin (i.e., stream mouth locations)
3. Location so that data obtained at trend-monitoring stations may be combined with data from adjacent stations to isolate effects of suspected trend causes

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

4. Location such that the best available estimate of cross-sectional stream quality is given by a single grab sample

5. Avoidance of sites where local effects, such as planned highway construction, stream channelization, etc., would produce spurious results

6. Location to facilitate access to minimize sampling-team travel requirements

Trend-monitoring stations may be minimized by siting these on larger streams or rivers downstream from areas experiencing energy resource development. This is feasible because of the geographic distribution of energy reserves and development activities (Figures 2, 3, 4, 5, 8, and 11). Such a network should be sufficient to detect trends in surface-water quality caused by development of energy resources. They will, however, also detect trends resulting from other activities in the upstream drainage. In order to determine the cause of an observed trend, it will be necessary to utilize other sources of data.

In general, National Stream Quality Accounting Network (NASQAN) stations are suitably located to serve for monitoring western energy resource development impact. NASQAN is a nationwide system of water-quality monitoring stations located at major hydrographic subdivisions of river basins. The network's objectives include determining areal variability and detection of long-term (75 year) changes in stream quality. The location of stations suitable for monitoring energy resource development impact on water quality is indicated in Figures 16 and 17, and tabulated in Table 18 (Ficke and Hawkinson 1975).

In addition to the NASQAN stations above, stations near the mouths of the Blacks Fork, White, San Rafael, and Price Rivers, Piceance Creek, the Green River at Green River, Wyoming, the North Fork of the Gunnison River near Somerset, Colorado, and the Medicine Bow River above Seminole Reservoir, Wyoming, need to be added. Existing USGS water-quality stations are satisfactorily situated for use at each of these locales. These 25 stations would be sampled on an 8-to 13-day basis. The data obtained will provide for trend analyses but will have to be augmented by data from other stations to determine the cause of any observed trends.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD.
BEGIN
SECTIONS
HERE

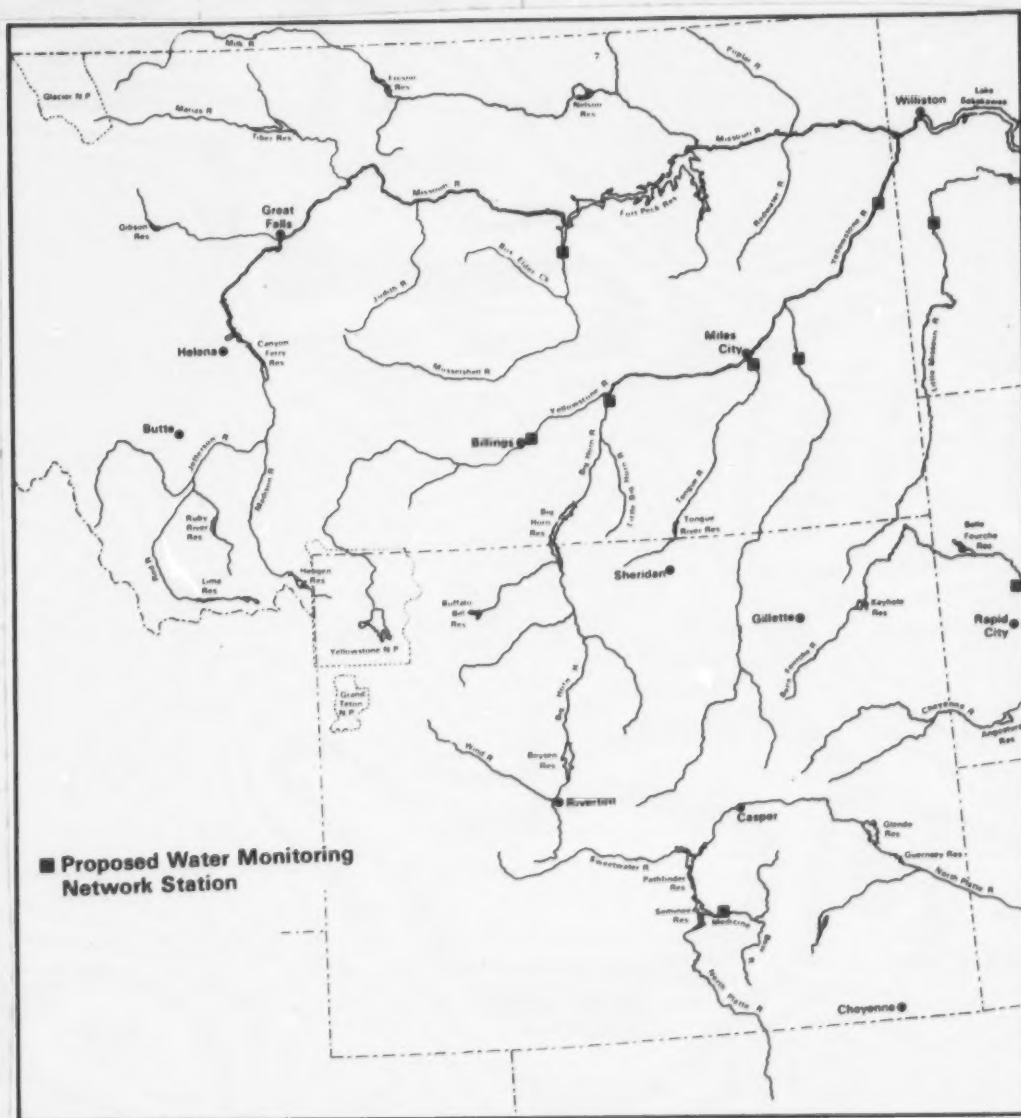


Figure 16. Recommended stations for monitoring western energy resource development impact on surface-water quality, Missouri River system.

BEGIN
LAST LINE
OF TEXT

3/8"

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

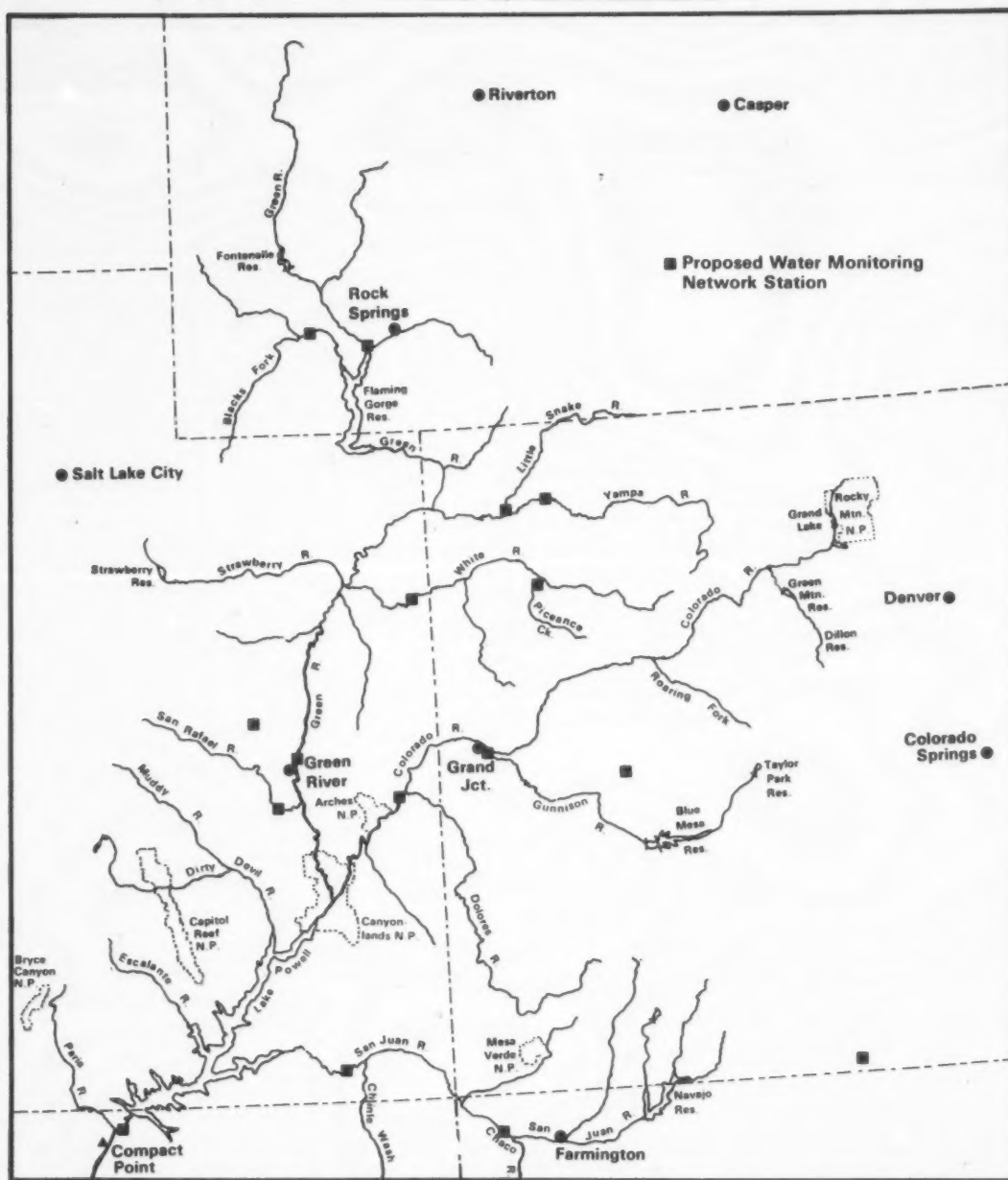
BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE



BEGIN
LAST LINE
OF TEXT

Figure 17. Recommended stations for monitoring western energy resource development impact on surface-water quality, Colorado River system.

3/8"

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

TABLE 18. NASQAN STATION DESCRIPTIONS

USGS Station No.	Station Name	State	Latitude	Longitude
09380000	Colorado River at Lees Ferry	AZ	36°52'	111°35'
08251500	Rio Grande near Lobatos	CO	37°65'	105°45'
09152500	Gunnison River near Grand Junction	CO	38°59'	108°27'
09251000	Yampa River near Maybell	CO	40°30'	108°02'
09260000	Little Snake River near Lily	CO	40°33'	108°25'
06130500	Musselshell River at Mosby	MT	47°00'	107°53'
06214500	Yellowstone River at Billings	MT	45°48'	108°28'
06294700	Bighorn River at Bighorn	MT	40°69'	107°28'
06308500	Tongue River at Miles City	MT	46°22'	105°48'
06326500	Powder River near Locate	MT	46°27'	105°19'
06329500	Yellowstone River near Sidney	MT	47°41'	104°09'
09368000	San Juan River at Shiprock	NM	36°48'	108°44'
06337000	Little Missouri River near Watford City	ND	47°35'	103°15'
06438000	Belle Fourche River near Elm Springs	SD	44°22'	102°34'
09180500	Colorado River near Cisco	UT	38°49'	109°18'
09315000	Green River at Green River	UT	38°59'	110°09'
09379500	San Juan River near Bluff	UT	37°09'	109°52'

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

80

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

RECOMMENDED DESIGN

A monitoring network designed to detect trends in water quality over a two- to four-year period is recommended in order to assess the impact of energy resource development. The network is specifically designed to address ongoing and projected developments in the Rocky Mountain and Upper Colorado Basin States (Figure 1). Radiological parameters are not included in this design.

Energy resource development in the area will largely be the exploitation of fossil fuels and uranium reserves. In particular, extraction and conversion of coal and oil shale kerogens is expected. Known resources are limited to a relatively few watersheds, and their development tends to cluster activities into fairly small geographic areas. Because of this, monitoring efforts can be limited to a small number of stations. Twenty-five stations were selected from existing USGS monitoring stations for inclusion into a monitoring network. These stations were selected on major streams draining areas of ongoing development and are listed in Table 1 and indicated in Figures 16 and 17.

Continuous monitoring of flow, pH, conductivity, temperature, and, if possible, dissolved oxygen and chloride is recommended. Data obtained may be expressed as daily means. Grab samples of water should be collected every 8 to 13 days and analyzed for the chemicals indicated in Table 2.

Research on the nature and amount of organic compounds produced and released by energy resource development activities must continue. Although present state-of-the-art does not permit routine monitoring of most organic compounds or compound classes, identification of chemicals of primary concern must be accomplished and monitoring techniques developed. Those compounds or compound classes (i.e., phenols) for which analytical techniques are available should be monitored on a regular basis. It is recommended that surveys of all organic compounds present in energy resource development effluents be made on an annual basis or in conjunction with specific experiments.

Sediment samples containing significant amounts of the silt-clay fraction should be collected at or near water-quality stations at least each quarter. Desired analyses are indicated in Table 2. In addition, sediment samples should be collected annually from organic-rich backwater areas near the site. These should be subjected to organic analyses.

BEGIN
LAST LINE
OF TEXT

Biomonitoring should be a major component of the network. Fish tissues should be analyzed for EPA-specified toxic pollutants. Fecal coliform and fecal streptococci levels should be monitored monthly. Periphyton production and taxonomy should be determined seasonally using artificial substrates.

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

Monitoring of macrobenthic communities and populations should be conducted seasonally in riffle areas near the stations. A small fish collection should also be made on an annual or every-other-year basis. Representative biological samples should be preserved and stored for future, yet-to-be-developed analyses.

In order to implement the sampling program outlined above, it may be necessary to drop stations located elsewhere. Modern monitoring theory supports this decision--it is more efficient to collect many samples at fewer stations than to collect the same number of samples distributed over a large number of stations. Careful consideration as to which stations to drop is essential because nonnetwork station data are needed to determine the cause of any detected trends.

Finally, any data collected are only useful if they are available. It is highly recommended that careful, timely storage in a unified computer data base be accomplished. Development of data analysis and interpretation procedures should occur concurrently with data collection and be made readily available to area researchers. A document outlining procedures to identify data trends or other interpretive outputs should be prepared and routine methods applied to all monitoring network stations on a regular basis.

Storage of data obtained in readily accessible computer data storage banks is necessary for a meaningful monitoring program. STORET is recommended for storage of water-quality data. Biological or other data unacceptable to STORET should be stored elsewhere on the EPA computer to allow convenient interface with the water-quality data. Software and other necessary procedures to facilitate merger of STORET data with those in other Federal data bases (e.g., WATSTORE) should be developed and made accessible to researchers.

This paper describes a water-sampling network designed to assess energy resource development impact on water quality through detection of temporal trends. Stations and parameters were held to a minimum to accomplish this task. Addition of stations or parameters is to be encouraged. At specific areas, local conditions may well require additional parameters.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

82

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

REFERENCES

- Adams, W., 1975. "Western Environmental Monitoring Accomplishment Plan Draft Report," U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Las Vegas, Nev. 48 pp. (Unpublished document.)
- Albers, J. P., W. J. Bawiec, L. F. Rooney, G. H. Goudarzi, and G. L. Shaffer, 1976. "Demand and Supply of Nonfuel Minerals and Materials for the United States Energy Industry, 1975-90-A Preliminary Report," USGS Prof. Paper 1006-A.B., USGS, Dept. of Interior, GPO, Washington, D.C. 56 pp.
- Attari, A., J. Pau, and M. Mesinger, 1976. "Fate of Trace and Minor Constituents of Coal During Gasification," U.S. Environmental Protection Agency, Ind. Env. Rsch. Lab., EPA 600/2-76-258, Research Triangle Park, N.C. NTIS PB 270 913.
- Bates, E. R., and T. L. Thoen, 1979. "Pollution Control Guidance for Oil Shale Development," Unpublished Initial Draft Report, U.S. Environmental Protection Agency, Region VIII, Denver, Colo. 428 pp.
- Beckers, C. V., S. G. Chamberlain, and G. P. Grimsrud, 1972. "Qualitative Methods for Preliminary Design of Water Quality Surveillance Systems," U.S. Environmental Protection Agency, Office of Research and Monitoring, Socioeconomic Environmental Studies Series EPA-R5-72-001, Washington, D.C. 266 pp.
- Beckers, C. V., and S. G. Chamberlain, 1974. "Design of Cost-Effective Water Quality Surveillance Systems," U.S. Environmental Protection Agency, Office of Research and Development, U.S. EPA 600/5-74-004, Washington, D.C. 413 pp.
- Berndt, R. A., 1975. "Design of a Water Quality Monitoring Network." MS Thesis, Dept. of Env. Sciences and Eng., North Carolina Univ., Chapel Hill. Also as USDI Office of Water Resources and Technology Dept. A-065-NC(1), Washington, D.C. 89 pp. NTIS PB 268 520.
- Christensen, H. E., and E. J. Fairchild (Eds.), 1976. "Suspected Carcinogens, 2nd Edition," U.S. Department of Health, Education and Welfare, National Institute of Occupational Safety and Health, Cincinnati, Ohio. 251 pp.
- Chu, T. -Y. J., P. A. Krenkel, and R. J. Ruane, 1976. "Characterization and Reuse of Ash Pond Effluents In Coal-Fired Power Plants," pp. 2494-2508. In: Jour. Water Poll. Cont. Fed., Vol. 50, No. 11, Nov. 1978. Washington, D.C.

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
LAST LINE
OF TEXT

3/8"

83

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

Clarke, R. McV., 1974. "The Effects of Effluents From Metal Mines On Aquatic Ecosystems In Canada," Technical Rept. 488, Fisheries and Marine Service, Dept. of the Environment, Winnipeg, Manitoba. 150 pp.

Cleary, E. J., 1977. "Perspective On River-Quality Diagnosis." pp. 522-527. In: Journal of the American Water Works Association, Vol. 69, No. 10, Oct. 1977, Denver, Colo.

Conkle, N., V. Elizy, and K. Murthy, 1974. "Environmental Considerations for Oil Shale Development," U.S. Environmental Protection Agency, EPA-650/2-74-099, Washington, D.C., 114 pp. NTIS PB 241 942.

Corsetino, J. S., 1976. "Projects to Expand Fuel Sources in Western States," U.S. Bureau of Mines, Information Circular No. 8719, Denver, Colo. 208 pp.

Cox, E., and R. Walker, 1977. "Recognition of Aesthetic Values in Water Law," pp. 31-34. In: Jour. Water Works Assn., Jan. 1977.

Crawford, K. W., Ch. H. Prien, L. B. Baboolal, C. C. Shih, and A. A. Lee, 1977. "A Preliminary Assessment of the Environmental Impacts From Oil Shale Developments," U.S. Environmental Protection Agency, Ind. Env. Rsch. Lab., EPA-600/7-77-069, Cincinnati, Ohio. 174 pp.

Cushman, R. M., S. G. Hildebrand, R. H. Strand, and R. M. Anderson, 1977. "The Toxicity of 35 Trace Elements in Coal to Freshwater Biota: A Data Base With Retrieval Capabilities," Oak Ridge National Lab., ORNL/TM-5793, Oak Ridge, Tenn. 50 pp. NTIS ORNL/TM-5793.

Dean, W. E., 1976. "Geochemistry of Green River Oil Shale." In: USGS, 1976, Geochemical Survey of Western Energy Regions, Third Annual Progress Report, July 1976, pp. 48-56, USGS, Open File Report 76-729, Denver, Colo.

Environmental Monitoring and Support Laboratory, Las Vegas, 1977. "Western Energy/Environment Monitoring Atlas," U.S. EPA, EPA-600/7-77-047a, Las Vegas, Nev. 30 pp.

Everett, L. G., 1979. "Groundwater Quality Monitoring of Western Coal Stripmining: Identification and Priority Ranking of Potential Pollution Sources," U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, EPA-600/7-79-024, Las Vegas, Nev. 264 pp.

Federal Energy Administration, 1974. "Project Independence Blueprint Final Task Report. Coal." 175 pp.

Federal Power Commission, 1977. "Principal Electric Facilities: Northwestern and Southwestern Regions, 1977," Bureau of Power, USGPO, Supt. of Doc., Washington, D.C. (2 maps)

BEGIN
LAST LINE
OF TEXT

Ferguson, J. F., and J. Gavis, 1972. "A Review of the Arsenic Cycle in Natural Waters." In: Jour. of Water Resources, Vol. 6, pp. 1259-1274.

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

Ficke, J. F., J. B. Weeks, and F. A. Welder, 1974. "Hydrologic Data From Piceance Basin, Colorado," Colorado Water Resources Basic-Data Release No. 31, Colorado Dept. of Natural Resources, Denver, Colo. 246 pp.

Ficke, J. F., and R. O. Hawkinson, 1975. "The National Stream Quality Accounting Network (NASQAN)--Some Questions and Answers." USGS, Circular 719, Reston, Va. 23 pp.

Ford, Bacon and Davis Utah, Inc., 1977a. "Summary of the Phase II, Title I Engineering Assessment of Inactive Uranium Mill Tailing, Green River Site, Green River, Utah," Ford, Bacon and Davis Utah, Inc., Salt Lake City, Utah. 153 pp. NTIS: GJT-14.

Ford, Bacon and Davis Utah, Inc., 1977b. "Summary of the Phase II, Title I Engineering Assessment of Inactive Uranium Mill Tailing, Green River Site, Green River, Utah," Ford, Bacon and Davis Utah, Inc., Salt Lake City, Utah. 48 pp. NTIS: GJT-145.

Ford, Bacon and Davis Utah, Inc., 1977c. "Summary of the Phase II, Title I Engineering Assessment of Inactive Uranium Mill Tailing, Spook Site, Converse County, Wyoming," Ford, Bacon and Davis Utah, Inc., Salt Lake City, Utah. 45 pp. NTIS: GJT-155.

Ford, Bacon and Davis Utah, Inc., 1977d. "Summary of the Phase II, Title I Engineering Assessment of Inactive Uranium Mill Tailing, Riverton Site, Riverton, Wyoming," Ford, Bacon and Davis Utah, Inc., Salt Lake City, Utah. 52 pp. NTIS: GJT-195.

Gehrs, C. W., 1976. "Comments During Panel Discussion On Liquid Residuals," pp. 193-199. In: Schmidt-Collerus, J. J., and F. Bonomo (Eds.), 1976. "Proceedings of the First Symposium on Management of Residues From Synthetic Fuels Production," held at Denver, Colo., May 25-27, 1976, Denver Rsch. Inst., Univ. of Denver. NSF/RA-770073 Rann Doc Center. 359 pp. NTIS PB 268 464.

Geraghty, J., W. Miller, Van Der Leeden, and F. L. Troise, 1973. "Water Atlas of the United States," Water Information Center, Port Washington, N.Y. 122 plates.

Gluskoter, H. J., R. R. Ruch, W. G. Miller, R. A. Cahill, G. B. Dreher, and J. K. Kuhn, 1977. "Trace Elements In Coal: Occurrence and Distribution," U.S. Environmental Protection Agency, Ind. Env. Rsch. Lab., EPA 600/7-77-064, Research Triangle Park, N.C. 165 pp. NTIS PB 270 922.

Gold, H., and D. J. Goldstein, 1978. "Water-Related Environmental Effects in Fuel Conversion: Volume 1, Summary," U.S. Environmental Protection Agency, Ind. Env. Rsch. Lab., EPA-600/7-78-197a, Research Triangle Park, N.C. 253 pp.

BEGIN
LAST LINE
OF TEXT

Goldstein, D. J., and D. Yung, 1977. "Water Conservation and Pollution Control in Coal Conversion Processes," U.S. Environmental Protection Agency, Ind. Env. Rsch. Lab., EPA-600/7-77-065, Research Triangle Park, N.C. 486 pp. NTIS PB 269 568.

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

Gould, A., 1977. "Preserving Instream Flows Under the Appropriation Doctrine: Problems and Possibilities," pp. 3-21. In: "Protecting Instream Flows Under Western Water Laws: Selected Papers," L. Lamb, (Ed.), 1977, Cooperative Instream Flow Service Group, Western Energy and Land Use Team, Off. of Biol. Services, Fish and Wildlife Services, Department of the Interior. FWS/OB7-77/47. 67 pp. NTIS PB 272 993.

Harza Engineering Company, 1976. "Analysis of Energy Projections and Implications for Resource Requirements," Chicago, Ill. 130 pp.

Hayes, E. T., 1979. "Energy Resources Available to the United States, 1985 to 2000," pp. 233-239. In: Science, Vol. 203, No. 4377, 19 January.

Hem, J. D., 1970. "Study and Interpretation of the Chemical Characteristics of Natural Water, Second Edition," USGS Water-Supply Paper 1473, U.S. GPO, Washington, D.C. 363 pp.

Hughes, E. E., E. M. Dickson, and R. A. Schmidt, 1974. "Control of Environmental Impacts From Advanced Energy Sources," U.S. Environmental Protection Agency, EPA-600/2-74-002, Washington, D.C. 326 pp.

Humenick, M. J., and C. F. Mattox, 1978. "Groundwater Pollutants From Underground Coal Gasification," pp. 463-469. In: Water Research, Vol. 12, No. 7, July 1978. Pergamon Press Ltd., London, England.

Hutchinson, G. E., 1957. "A Treatise on Limnology," Vol. 1, Geography, Physics, and Chemistry, John Wiley and Sons, Inc., New York, N.Y. 1015 pp.

Institute for Environmental Studies, 1975. "Oil Shale Development In Western Colorado: Water and Related Land Impacts," IES Report 48, Univ. of Wisconsin, Madison, Wisc. 254 pp.

Iorns, W. V., C. H. Hembree, and G. L. Oakland, 1965. "Water Resources of the Upper Colorado River Basin - Technical Report," U.S. Geological Survey Professional Paper 441, Washington, D.C. 370 pp.

Jones, D. C., W. C. Clark, J. C. Lacy, W. F. Holland, and E. D. Snethness, 1977. "Monitoring Environmental Impacts of the Coal and Oil Shale Industries - Research and Development Needs," U.S. Environmental Protection Agency, EPA-600/7-77-015, Washington, D.C. 193 pp.

Judy, C. H., and A. Gartner, 1977. "Areawide Water Quality Management in an Energy Development Area," pp. 835-841. In: Water Resources Bulletin, Vol. 13, No. 4, Aug. 1977, American Water Resources Assn., Washington, D.C.

Kathuria, D. V., M. A. Nawrocki, and B. C. Becker, 1976. "Effectiveness Of Surface Mine Sedimentation Ponds," U.S. Environmental Protection Agency, Ind. Env. Rsch. Lab., EPA-600/2-76-117, Cincinnati, Ohio. 109 pp. NTIS PB 258 917.

BEGIN
LAST LINE
OF TEXT

3/8"

86

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

- Kinney, W. L., A. N. Brecheisen, and V. W. Lambou, 1979. "Surface Water Quality Parameters for Monitoring Oil Shale Development," U.S. Environmental Protection Agency, Environmental Monitoring and Systems Laboratory, EPA-600/4-79-018, Las Vegas, Nev. 156 pp.
- Klein, D. H., A. W. Andren, J. A. Carter, J. F. Emery, C. Feldman, W. Fulkerson, W. S. Lyon, J. C. Ogle, Y. Talmi, R. I. Van Hook, and N. Bolton, 1975. "Pathways of Thirty-Seven Trace Elements Through Coal Fired Power Plants," pp. 973-979. In: Env. Sci. and Tech., Vol. 9, No. 10, Oct. 1975.
- Larson, W. C., 1978. "Uranium In Situ Leach Mining In The United States," USDI, Bureau of Mines Info. Circ. 8777, Washington, D.C. 68 pp.
- Lettermaier, D. P., 1975. "Design of Monitoring Systems for Detection of Trends in Stream Quality," Univ. of Washington, Dept. of Civil Engineering Tech. Rept. 39, Seattle, Wash. 217 pp. NTIS PB 272 814.
- Lettermaier, D. P., 1976. "Detection of Trends in Water Quality Data From Records With Dependent Observations." In: Water Resources Research, Vol. 12, No. 5, pp. 1037-1046, Oct. 1976.
- Lettermaier, D. P., 1978. "Design Considerations for Ambient Stream Quality Monitoring," pp. 884-902. In: Water Resources Bulletin, Vol. 14, No. 4, August 1978. American Water Resources Assn., Washington, D.C.
- Lewis, D. H., 1976. "Optimization of State Water Quality Monitoring Systems." In: Jour. of Computers and Operations Research, Vol. 3, No. 2-3, pp. 127-143. Pergamon Press, August 1976. Also as EPA Report EPA-600/J-76-029, Corvallis, Ore. NTIS PB 265 313.
- Libicki, J., 1978. "Effects of the Disposal of Coal Waste and Ashes in Open Pits," U.S. Environmental Protection Agency, Ind. Env. Rsch. Lab., EPA-600/7-78-067, Cincinnati, Ohio. 298 pp. NTIS PB 284 013.
- Loogna, G. O., 1972. "The Carcinogenic Properties of Oil Shale Products and the Prophylaxis of Cancer." In: Naachi-prakt Deyatel. Inst. Eksp, Klino, Tallin, pp. 105-113. Translation by Leo Kanner Assn., U.S. Environmental Protection Agency, EPA-TR76-54, Washington, D.C. 16 pp. NTIS: PB 258 920-T.
- Mason, B., 1952. "Principles of Geochemistry," John Wiley and Sons, Inc., New York, N.Y. 310 pp.
- McKee, J. E., and H. W. Wolf, 1963. "Water Quality Criteria," State Water Quality Control Board, Resources Agency of California, Pub. No. 3-A, Sacramento, Calif. 548 pp.
- Melancon, S. M., T. Simonian, and R. W. Thomas, 1979a. "Assessment of Energy Resource Development Impact on Water Quality: The San Juan River Basin," U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, EPA-600/7-79-235, Las Vegas, Nev. 151 pp.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

87

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

Melancon, S. M., B. C. Hess, and R. W. Thomas, 1979b. "Assessment of Energy Resource Development Impact on Water Quality; The Tongue and Powder River Basins," U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, EPA-600/7-79-249, Las Vegas, Nev. 222 pp.

Moss, M. E., D. P. Lettermaier, and E. F. Wood, 1978. "On The Design Of Hydrologic Data Networks," pp. 772-775. In: EOS Trans. AGU, Vol. 59, No. 6, Washington, D.C.

National Academy of Sciences, 1973. "Water Quality Criteria 1972," U.S. Environmental Protection Agency, EPA/R3/73-003, Washington, D.C. 594 pp.

National Petroleum Council, 1973. "U.S. Energy Outlook: Oil and Gas Availability," National Petroleum Council, Washington, D.C. 768 pp.

Native American Natural Resources Development Federation of the Northern Great Plains (NANROF), 1974. "Declaration of Indian Rights to the Natural Resources in the Northern Great Plains States." U.S. Bureau of Indian Affairs, Washington, D.C. 25 pp.

NUS Corporation, 1970. "Design of Water Quality Surveillance System," Federal Water Quality Administration, U.S. Department of Agriculture Federal Water Pollution Control Research Series 16090 DBJ 08/70, Washington, D.C. 301 pp.

Office of Technology Assessment, 1978. "A Technology Assessment of Coal Slurry Pipelines," Congress of the United States, U.S. GPO, Washington, D.C. 155 pp.

Pellizzari, E. D., 1978. "Identification of Components of Energy-Related Wastes and Effluents," U.S. Environmental Protection Agency, Office of Rsch. and Devl., EPA-600/7-78-004, Athens, Ga. 500 pp.

Price, D., and T. Arnow, 1974. "Summary Appraisals of the Nation's Ground-Water Resources - Upper Colorado River," USGS Prof. Paper 813-G, U.S. Geological Survey, Washington, D.C. 40 pp.

Project Gasbuggy Joint Office of Information, 1967. "Project Gasbuggy: A Government-Industry Natural Gas Production Stimulation Experiment Using Nuclear Explosives," U.S. AEC-EL Paso Natural Gas Company - Department of Interior. 20 pp.

Radian Corporation, 1975. "Coal Fired Power Plant Trace Element Study Station I, Station II, Station III," U.S. Environmental Protection Agency, Office of Energy Activities, EPA-68-01-2663, Denver, Colo. 294 pp. NTIS PB 283 278.

Ray, S. S., and F. G. Parker, 1977. "Characterization of Ash From Coal-Fired Plants," U.S. Environmental Protection Agency, Office of Rsch. and Devl., EPA-600/7-77-010, Washington, D.C. 130 pp.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

Reed, A. K., H. C. Meeks, S. E. Pomeroy, and V. Q. Hale, 1976. "Assessment of Environmental Aspects of Uranium Mining and Milling," U.S. Environmental Protection Agency, Ind. Env. Rsch. Lab., EPA-600/7-76/036, Cincinnati, Ohio. 59 pp.

Ringrose, C. D., R. W. Klusman, and W. E. Dean, 1976. "Soil Chemistry in the Piceance Creek Basin," pp. 101-111. In: USGS, 1976, Geochemical Survey of Western Energy Regions, Third Annual Progress Report, July 1976, USGS, Open File Report 76-729. Denver, Colo.

Sanders, T. G., and D. D. Adrian, 1978. "Sampling Frequency for River Quality Monitoring," pp. 569-576. In: Water Resources Rsch., Vol. 14, No. 4. American Geophysical Union, Washington, D.C.

Sharp, W. E., 1971. "A Topologically Optimum Water Sampling Plan for Rivers and Streams," pp. 1641-46. In: Water Resources Research, Vol. 7, No. 6, Dec. 1971.

Sherwani, J. K., and D. H. Moreau, 1975. "Strategies for Water Quality Monitoring," North Carolina Water Resources Institute, UNC WRRRI 75-107, Raleigh, N.C. 150 pp. NTIS PB 245 765.

Shih, C. C., C. H. Prien, T. D. Nevens, and J. E. Cotter, 1976. "Technology Overview Reports for Eight Shale Oil Recovery Processes," Prepublication Copy, U.S. Environmental Protection Agency, Ind. Env. Rsch. Lab., Cincinnati, Ohio. 110 pp.

Shupe, Stephen J., 1978. "Instream Flow Requirements in the Powder River Coal Basin," pp. 349-358. In: Water Resources Bulletin, Vol. 14, No. 2, April, 1978. American Water Resources Assn., Washington, D.C.

Slawson, G. C. (Ed.), 1979. "Groundwater Quality Monitoring of Western Oil Shale Development: Identification and Priority Ranking of Potential Pollution Sources," U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, EPA-600/7-79-023, Las Vegas, Nev. 240 pp.

Steele, T. D., E. J. Gilroy, and R. O. Hawkinson, 1974. "An Assessment of Areal and Temporal Variations in Streamflow Quality Using Selected Data From the National Stream Quality Accounting Network," USGS, Open File Report 74-217, Reston, Va. 210 pp.

Stumm, W., and J. J. Morgan, 1970. "Aquatic Chemistry," Wiley-Interscience, New York, N.Y. 583 pp.

Taylor, O. J., 1978. "Summary Appraisals of the Nation's Ground-Water Resources - Missouri Basin Region," USGS Prof. Paper 813-8, U.S. Geological Survey, Washington, D.C. 41 pp.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

Taylor, W. D., S. C. Hern, L. R. Williams, V. W. Lambou, M. K. Morris, and F. A. Morris, In Press. "Phytoplankton Water Quality Relationships in U.S. Lakes, Part VI: Common Phytoplankton Genera From Eastern and Southeastern Lakes," and "Part VII: Comparisons of Some New and Old Indices and Measurements of Trophic State," U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Las Vegas, Nev.

Theis, T. L., J. D. Westrick, C. L. Hsu, and J. J. Marley, 1976. "Field Investigation of Trace Metals in Groundwater From Fly Ash Disposal," pp. 2457-2469. In: Jour. Water Poll. Cont. Fed., Vol. 50, No. 11, Nov. 1978, Washington, D.C.

Thomas, R. W., T. L. Thompson, V. W. Lambou, and L. Zeliph, In Press. "Ambient Water Quality in the Western Energy Resource Development Region," U.S. Environmental Protection Agency, Environmental Monitoring and Systems Laboratory, Las Vegas, Nev.

Trumbull, J., 1960. Coal Fields of the United States, Sheet 1, USGS, Reston, Va. (map).

U.S. Atomic Energy Commission, 1972. "Environmental Statement, Wagon Wheel Gas Stimulation Project, Sublette County, Wyoming," Washington, D.C., WASH-1524. 204 pp.

U.S. Bureau of Reclamation, 1977a. "El Paso Coal Gasification Project, San Juan County, New Mexico, Final Environmental Statement INTFES 77-03, Vol. 1," U.S. Department of Interior, Washington, D.C. 550 pp.

U.S. Bureau of Reclamation, 1977b. "Report on the Western Energy Expansion Study," U.S. Department of Interior, Washington, D.C. 145 pp.

U.S. Department of the Interior, 1973. "Final Environmental Impact Statement for the Prototype Oil Shale Leasing Program, Vol. 1, Regional Impacts of Oil Shale Development," U.S. Environmental Protection Agency, Ind. Env. Rsch. Lab., EPA-600/7-77-069, Cincinnati, Ohio. 186 pp.

U.S. Environmental Protection Agency, 1974. "Northern Great Plains Resources Program Accomplishment Plan Region VIII," U.S. Environmental Protection Agency, Region VIII, Denver, Colo. 189 pp.

U.S. Environmental Protection Agency, 1976a. "Surface Coal Mining in the Northern Great Plains of the Western United States," Region VIII, OEA 76-1, Denver, Colo. 146 pp.

U.S. Environmental Protection Agency, 1976b. "Quality Criteria for Water," EPA-440/9-76-023, Washington, D.C. 501 pp.

U.S. Geological Survey, 1970. "The National Atlas of the United States of America," U.S. Department of Interior, Washington, D.C. 417 pp.

BEGIN
LAST LINE
OF TEXT

U.S. Geological Survey, 1977. "National Handbook of Recommended Methods for Water-Data Acquisition," U.S. Department of Interior, Reston, Va. 191 pp.

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLU-
STRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

Univ. of Oklahoma and Radian Corporation, 1977. "Energy From the West: A Progress Report of a Technology Assessment of Western Energy Resource Development," 2 Vols., U.S. Environmental Protection Agency, Off. of Energy Development, EPA-600/7-77-072 a and b, Washington, D.C. 805 pp.

Van Meter, W. P., and R. E. Erickson, 1976. "Environmental Effects From Leaching of Coal Conversion By-Products: Interim Report for the Period Jan. - Mar., 1976," Univ. of Montana, Missoula, Mont., 12 pp. NTIS FE 2019-3.

Van Voast, W. A., and R. B. Hedges, 1975. "Hydrologic Aspects of Existing and Proposed Strip Coal Mines Near Decker, Southeastern Montana," Mont. Bur. of Mines and Geol., Bull. No. 97, Helena, Mont. 31 pp.

Wachter, R. A., and T. R. Blackwood, 1978. "Source Assessment: Water Pollutants From Coal Storage Areas," U.S. Environmental Protection Agency, Ind. Env. Rsch. Lab. EPA-600/2-78-004m, Cincinnati, Ohio. 160 pp.

Ward, R. C., 1973. "Data Acquisition Systems in Water Quality Management," U.S. Environmental Protection Agency, Office of Rsch. and Devl., EPA-R5-73-014, Washington, D.C. 259 pp.

Ward, R. C., and K. S. Nielson, 1978. "Evaluating the Sampling Frequencies of Water Quality Monitoring Networks," U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, EPA-600/7-78-169, Las Vegas, Nev. 40 pp.

Water Resources Work Group, 1971. "Upper Colorado Region Comprehensive Framework Study, Appendix V, Water Resources," Upper Colorado Region State-Federal Inter-Agency Group for the Pacific Southwest Inter-Agency Committee, Water Resources Council. 66 pp.

Weeks, J. B., and F. A. Welder, 1974. "Colorado Water Resources Basic-Data Release 35: Hydrologic and Geophysical Data From the Piceance Basin, Colorado," Colorado Dept. of Nat. Resources, Denver, Colo. 121 pp.

Wewerka, E. M., J. M. Williams, P. L. Wanek, and J. D. Olsen, 1976. "Environmental Contamination From Trace Elements in Coal Preparation Wastes: A Literature Review and Assessment," Environmental Protection Agency, EPA-600/7-76-007/ERDA-6600-MS, Research Triangle Park, N.C., 69 pp. and Los Alamos Scientific Lab., University of California, Los Alamos, N.M.

Wolman, M. G., 1971. "The Nation's Rivers," pp. 909-923. In: Science, Vol. 174, No. 4012.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA,
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

APPENDIX

RATIONALE FOR SELECTION OF ELEMENTS AND ELEMENTAL FORMS
FOR MONITORING

Aluminum is present in high concentrations in minerals associated with oil shales, and alum may be used as a coagulant during water treatment. Dissolved aluminum has been reported lethal to fish in concentrations as low as 0.07 milligrams/liter (mg/l) (McKee and Wolf 1963; Clarke 1974). Toxic effects from suspended aluminum hydroxides were observed in rainbow trout (Salmo gairdneri) (Clarke 1974). Hem (1970) observed that small aluminum hydroxide crystals less than 0.10 micron in diameter had considerable chemical and physical stability and would pass through a 0.45-micron filter. Many aluminum salts are insoluble, and as a major constituent of the Earth's crust, total aluminum levels should be relatively high and variable. It is recommended that dissolved aluminum be monitored.

Arsenic is a cumulative poison to humans and is a suspected carcinogen (Christensen and Fairchild 1976). Arsenic is concentrated in runoff from western coal stockpiles (Wachter and Blackwood 1978) and fly ash, oil shales (Ringrose et al. 1976) and uranium tailings (Ford, Bacon and Davis Utah, Inc. 1977a, 1977b, 1977c, and 1977d). Ferguson and Gavis (1972) reviewed the arsenic cycle in natural waters but concluded that there is little capability to predict the fate of arsenic entering a lake or river. Total arsenic should be monitored at network stations.

Boron has an established criterion of 750 mg/liter for use as irrigation water (U.S. Environmental Protection Agency 1976b). It is readily solubilized and was found in high concentrations in ash pond sluice runoff (Chu et al. 1976) and beneath coal waste pits (Libicki 1978). Boron levels in semiarid western streams and ground waters are often elevated and unsuited for irrigation of sensitive crops. Weeks and Welder (1974) reported dissolved boron contents greater than 12,000 µg/liter from wells in the Piceance Basin. Boron levels in semiarid western streams and ground waters are often elevated and unsuited for irrigation of sensitive crops. (Kinney et al. 1979; Melancon et al. 1979a, 1979b). It is recommended that total boron concentrations be monitored at network stations.

Barium should be rapidly precipitated in western waters as insoluble carbonates or sulfates (U.S. Environmental Protection Agency 1976b). Although soluble barium salts are poisonous (National Academy of Sciences 1973), their rapid precipitation, relatively low toxicity to aquatic life (U.S. Environmental Protection Agency 1976; Clarke 1974), and generally low ambient concentrations throughout the area (Kinney et al. 1979; Melancon et al. 1979a, 1979b) lessen the degree of hazard. Barium is solubilized from fly

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
LAST LINE
OF TEXT

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

ash disposal ponds (Chu et al. 1976) and is used to treat wastes containing Ra-66 (Clarke 1974). Very high barium levels were reported by Weeks and Welder (1974) in well waters from the Piceance Basin. Monitoring of total barium concentrations at network stations is recommended.

Cadmium is concentrated in fly ashes but is not released in alkaline sluice waters (Chu et al. 1976). Libicki (1978) found cadmium concentrations increased in ground waters beneath coal waste disposal pits. Attari and Mesinger (1976) found cadmium in HYGAS quench water, and Pellizzari (1978) reported levels in excess of criteria in in situ coal gasification process and product waters. Cadmium is a cumulative poison and suspected carcinogen (U.S. Environmental Protection Agency 1976b). It is toxic to aquatic biota at very low concentrations (U.S. Environmental Protection Agency 1976b; National Academy of Science 1973; Clarke 1974). In addition, it acts synergistically with other metals and cyanides to increase toxicity (McKee and Wolf 1963). Data on ambient cadmium levels available in STORET are generally reported in multiples of 10 µg/liter, the present EPA standard for drinking water. Because of the present uncertainties regarding ambient levels of cadmium and its extreme toxicity, total concentrations of this element should be monitored using the greatest analytical precision and accuracy practical.

Chromium levels were enhanced in ground waters beneath uranium ore tailings (Ford, Bacon and Davis Utah, Inc. 1977a, 1977b, 1977c, and 1977d, and dissolved chromium is found in process and effluent streams (Reed et al. 1976). Chu et al. (1976) found that chromium in alkaline fly ash sluice waters exceeded water-quality criteria. Fish are fairly tolerant of chromium but some aquatic invertebrates are quite sensitive (U.S. Environmental Protection Agency 1976b). Total chromium should be monitored at network stations.

Copper toxicity varies by copper's chemical states, by water conditions, and by aquatic species. Copper is generally less toxic in highly alkaline waters. Sublethal effects are seen prior to acute exposure concentrations, and observed lethal levels for eggs and fry are substantially less than for adults (Clarke 1974). Copper is insoluble in the presence of iron sulfides; it will be immobilized if there is an oxygen deficit but will diffuse back into the water when the surface layers become oxidized (Hutchinson 1957). Copper was solubilized from fly ash pond effluents (Chu et al. 1976) and was increased in ground water beneath mine spoil disposal pits (Libicki 1978). Monitoring of total copper at network sites is recommended.

Fluorides appear to have toxic effects on fish beginning in the 1 to 2 mg/liter concentration range (McKee and Wolf 1963). The minimum drinking water standard is 1.4 mg/liter for average annual maximum daily temperatures of 26.3°C to 32.5°C, well above the area. Fluorides are generally discharged to the atmosphere during coal combustion (Ray and Parker 1977). Ringrose et al. (1976) found oil shales to be enhanced in fluoride over surrounding soils, and Pellizzari (1978) found high fluoride levels in regional ground waters both before and after in situ gasification. Weeks and Welder (1974) reported high fluoride content in well waters in the Piceance Basin. Fluoride ion concentrations should be monitored at network stations.

BOTTOM OF
IMAGE AREA:
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

BEGIN
LAST LINE
OF TEXT

3/8"

BEGIN
FIRST
LINE OF
TEXT
HERE

Typing Guide Sheet

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

Iron is the fourth most abundant element by weight in the Earth's crust (Mason 1952). Criteria for iron are established for water supplies (0.3 mg/liter) to prevent laundry staining (U.S. Environmental Protection Agency 1976b). Iron has been found toxic to fish at concentrations as low as 0.2 mg/liter, but waters that support good fish populations may have concentrations as high as 0.7 mg/liter (McKee and Wolf 1963). Clarke (1974) cites several researchers who demonstrated that $\text{Fe}(\text{OH})_2$ precipitation on gill structures is responsible for fish mortality. Hutchinson (1957) discussed the iron cycle in fresh water. High iron concentrations were found in effluents from coal stockpiles (Wachter and Blackwood 1978), in in situ post gasification well waters (Pellizzari 1978), and in some Piceance Basin well waters (Weeks and Welder 1974). Monitoring of total iron concentrations at network water-quality stations is recommended.

Gallium is a fairly common rare earth element. Scant toxicity data exist, but those that do indicate that gallium is relatively un toxic. Although concentrated in coal ash residues (Klein et al. 1975; Melancon et al. 1979a), it does not appear at high levels in most effluent or process streams where it is measured. Monitoring of gallium at network stations is not recommended unless it can be accomplished as part of a multielement analysis that includes other elements of interest.

Mercury is an element of great biological concern due to its toxicity at very low concentrations, its potential for bioaccumulation, its mobility, and its well documented affects upon humans. It is found at high levels in in situ post gasification ground waters, (Pellizzari 1978). Mercury is volatilized during coal combustion and much of it escapes to the atmosphere, although fly ash levels are also high (Ray and Parker 1977; Klein et al. 1975). Oil shales contain high levels of mercury (Ringrose et al. 1976) as do some retort process streams (Bates and Thoem 1979). Mercury is readily adsorbed on sediment and organic particles. It is recommended that total mercury be monitored at network stations.

Lithium has been reported as toxic to some crops at concentrations below 1 mg/liter (McKee and Wolf 1963). Lithium salts have relatively low toxicities for animals (Christensen and Fairchild 1976). Lithium may be concentrated in fly ash (Wewerka et al. 1976; Melancon et al. 1979a), and Pellizzari (1978) found it to be considerably enhanced in some process waters and in situ post gasification ground water. Because of its low toxicity, lithium is not recommended as a standard monitoring parameter unless it can be conveniently determined in multielement water-quality analyses.

Manganese is not considered a problem in natural waters. A criterion of 50 $\mu\text{g/liter}$ was established for public water supplies for taste considerations. Although it may be enhanced in coal or oil shale wastes, manganese does not appear to be present in leachates at concentrations significantly above those found in natural waters (Bates and Thoem 1979; Wachter and Blackwood 1978). Manganese is not recommended for monitoring at network stations unless it can be conveniently determined in multielement analyses.

BEGIN
LAST LINE
OF TEXT

Molybdenum is a relatively low toxicity element that is an essential trace mineral. It may be concentrated in coal ashes (Ray and Parker 1977; Wewerka

BOTTOM OF
IMAGE AREA;
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS.

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD:
BEGIN
SECTIONS
HERE

et al. 1976) and oil shales (Ringrose et al. 1976). Libicki (1978) reported it beneath coal waste dumps. It is also enhanced in spent-shale leachates (Bates and Thoem 1979). Because increases in total molybdenum may be effectively used to detect the presence of leachate or other waters, it is recommended for monitoring at network stations.

Nickel is found in coal stockpile leachates (Wachter and Blackwood 1978), in alkaline fly ash sluice water (Chu et al. 1976), and in some process waters (Pellizzari 1978; Bates and Thoem 1979) at enhanced levels. Nickel has been found to be toxic to plant life at concentrations as low as 500 µg/liter (U.S. Environmental Protection Agency 1976b) and may affect aquatic life at levels as low as 30 µg/liter (Clarke 1974). Nickel hydroxide has a low solubility and is strongly absorbed by iron and manganese oxides (Hem 1970). It is recommended that total nickel be monitored at network stations.

Lead, like mercury, is of intense environmental concern. It is a cumulative poison with a fairly low effects threshold (U.S. Environmental Protection Agency 1976b). Lead compounds generally have low solubilities, and most lead in natural waters is found adsorbed on clays or complexed with dissolved and suspended organics or with iron, aluminum, and manganese hydroxides (Clarke 1974). Lead is preferentially accumulated in fly ash (Ray and Parker 1977) and in some process waters (Pellizzari 1978). Lead concentrations in spent-shale leachates ranged from 5 to 17 µg/liter (Bates and Thoem 1979). In addition, lead and its compounds are widely used in construction, in various industrial processes, and as a fuel additive. Monitoring of total lead is recommended at network stations.

Sulfur is insoluble in water but may be present as colloids. It is usually present in water as sulfates, sulfites, sulfides, or more complex salts. In most waters the sulfites and sulfides are rapidly oxidized to sulfates (Clarke 1974). Sulfides, particularly hydrogen sulfide (undissociated H₂S), are lethal to fish, fry, or eggs at levels of 2 µg/liter (U.S. Environmental Protection Agency 1976b). Sulfides may be produced naturally during anaerobic conditions. Sulfides are also by-products from oil shale, coal gasification, and other processes (Slawson 1979). The location of monitoring stations on flowing streams should assure sufficient oxygen to eliminate most sulfides and convert them to sulfates. Monitoring for total sulfur, sulfides, or sulfites is not considered effective at network stations. As noted previously, it is recommended that sulfate be monitored. Monitoring for sulfides near ongoing fuel extraction or processing installations or in lakes at stations used to supplement network data is highly recommended.

Antimony tends to be precipitated in natural waters as oxides or sulfides (McKee and Wolf 1963). Few data are available as to its aquatic toxicity, but the National Academy of Sciences (1973) reported toxicities occurring at levels above 10 mg/liter. Antimony is found at high concentrations in coal stockpile effluent (Wachter and Blackwood 1978) and is concentrated in fly ash (Ray and Parker 1977; Klein et al. 1975). However, levels are below those reported as causing effects on biota. Monitoring of antimony is not recommended at network stations.

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
LAST LINE
OF TEXT

3/8"

95

PAGE NUMBER

BEGIN
FIRST
LINE OF
TEXT
HERE

Typing Guide Sheet

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

Selenium has an established Federal drinking-water standard of 10 µg/liter (PL 93-523, Section 1412). Western coals are rich in selenium, most of which is concentrated in the fly ash (Klein et al. 1975) or discharged to the atmosphere (Ray and Parker 1977). Chu et al. (1976) found selenium levels in alkaline fly ash pond sluice water to exceed water-quality standards, and Bates and Thoem (1979) reported concentrations in spent-shale leachates to range from 7 to 50 µg/liter. Selenium levels were found to exceed water-quality criteria in ground water beneath uranium tailing piles (Ford, Bacon and Davis Utah, Inc. 1977a, 1977b, 1977c, and 1977d). One case of fish mortalities caused by selenium released from bottom sediments and passed through the food chain is reported by the National Academy of Sciences (1973). Total selenium is recommended for monitoring at network stations.

Silicon is the second most abundant element in the Earth's crust, and silica is the most abundant mineral (Mason 1952). Silica (silicon dioxide) is largely insoluble in water but may occur as finely divided or colloidal suspended material (McKee and Wolf 1963). Hem (1970) and Strum and Morgan (1970) consider it likely that dissolved silicon is present as silicic acid ions ($H_3SiO_4^-$) or more complex species. Although silicon levels are likely to be enhanced from energy resource development activities, they are not likely to pose any environmental hazard. Monitoring of silicon concentrations is not recommended at network stations.

Strontium concentrations were five times higher beneath coal waste pits than in unaffected ground water (Libicki 1978). Strontium concentrations were also considerably greater in post in situ gasification well-water samples (Pellizzari 1978) and in spent-oil-shale leachates (Bates and Thoem 1979). Strontium is not absorbed readily by soils and consequently may travel easily in ground waters (McKee and Wolf 1963). Strontium is closely related to calcium and barium and commonly replaces them in minerals and bone structures. The radioisotope, Sr-90 is of environmental concern. Although this report does not address monitoring for radionuclides, Sr-90 should be monitored in ground waters near nuclear stimulation experiments. Routine monitoring of total or dissolved strontiums levels is not recommended at network stations.

Uranium is found both as an ore and concentrated in some coals. It has a relatively low chemical toxicity to aquatic life (McKee and Wolf 1973). Uranium may enter the environment from process-stream spills, in situ mining operations, or leaching of tailings ponds (Reed et al. 1976). Uranium may be concentrated by algae from several hundred to a thousand times greater than ambient water concentrations. Uranium levels in water may be the first indication of contamination from extraction operations. Therefore, monitoring of total uranium concentrations is recommended at all network stations.

Vanadium is closely associated with uranium deposits. It appears in both process and effluent streams (Reed et al. 1976) and was found to be enhanced in ground water beneath tailing piles (Ford, Bacon and Davis Utah, Inc., 1977a, 1977b, 1977c, and 1977d). Vanadium has low chemical toxicity (McKee and Wolf 1963) but may be of use as an indicator of tailing-pile leaching or pond seepage. It is recommended that total vanadium concentrations be monitored at network stations.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

96

PAGE NUMBER

EPA-287 (Cin.)
(4-78)

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD,
BEGIN
SECTIONS
HERE

Zinc has been found in coal stockpile effluents (Wachter and Blackwood 1978), spent-shale leachates (Bates and Thoen 1979), and ash pond effluents (Chu et al. 1976). Clarke (1974) reports sublethal effects on reproduction from zinc at concentrations as low as 180 $\mu\text{g/liter}$, and McKee and Wolf (1963) report lethal effects on trout ova and fry at concentrations as low as 10 $\mu\text{g/liter}$. These effects are somewhat mitigated in hard waters. Zinc concentrations in effluents and leachates are high enough to be of concern. It is recommended that total zinc concentrations be monitored at network stations.

6-1/2"

9-1/8"

BEGIN
LAST LINE
OF TEXT

3/8"

97

PAGE NUMBER

EPA-287 (Cin.)
(4-75)

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUSTRATIONS

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

P880-199839

TOP OF
IMAGE
AREA

EPA-600/4-80-036
July 1980

DROPPED
HEAD;
BEGIN
SECTIONS
HERE

WESTERN ENERGY RESOURCE DEVELOPMENT
A Network For Monitoring The Impact On
Surface Water Quality

by

R. W. Thomas
Environmental Monitoring Systems Laboratory
Las Vegas, Nevada 89114

6-1/2"

9 1/8"

BEGIN
LAST LINE
OF TEXT

ENVIRONMENTAL MONITORING SYSTEMS LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
LAS VEGAS, NEVADA 89114

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE

U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA-287 (Cin.)
(4-76)